



Does learning from prior collaboration help firms to overcome the ‘two-worlds’ paradox in university-business collaboration?

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ARTICLE INFO

Keywords:

Innovation
University
Collaboration
Learning

ABSTRACT

There is now substantial evidence of the positive contribution universities can make to helping firms' innovation. Building university-business collaborations, however, confronts the ‘two-worlds’ paradox, and the difference in institutional logics and priorities between businesses and universities. Here, we consider whether firms' experience from prior collaboration can generate learning which can help to overcome the two-worlds paradox and improve firms' ability to generate new-to-the-market innovations in collaboration with universities. Our analysis is based on panel data for UK companies and controls for the decision to innovate. We find evidence of significant learning effects which both increase the probability that firms collaborating with universities are able to develop new-to-the-market innovations and then benefit from those innovations. For smaller firms learning effects are strongest from prior collaboration with customers, while for medium and larger firms the strongest learning effects arise from prior collaboration with consultants.

1. Introduction

There is now substantial evidence from a range of countries on the positive role of universities in helping firms to innovate successfully (Petrizzelli, 2011; Laursen and Salter, 2004; Mansfield, 1995; Bellucci and Pennacchio, 2016). Paradoxically, however, there is also substantial evidence of the difficulties which firms, particularly perhaps smaller firms, encounter in establishing, structuring and sustaining productive collaborative relationships with universities (Laursen and Salter, 2004). Building university-business relationships confronts what Hall (2003) describes as the ‘two-worlds’ paradox, and the difference in institutional logics and priorities between businesses and universities (Dasgupta and David, 1994). This creates ‘orientation-related barriers’ and ‘transaction-related barriers’ to university-business collaboration reflected in conflicts over the creation or exploitation of knowledge, the timeliness (Hamisah et al., 2010) as well as the time-horizon of research projects (Dunowski et al., 2010), the prioritization and management of intellectual property (IP) and the bureaucracy of university administration (Bruneel et al., 2010)¹. This paradox often means that, despite significant impacts, firms rate universities contribution to their innovation relatively poorly (Howells et al., 2012) and that levels of university-business collaboration are below those between individual

firms (Drejer and Jørgensen, 2005).

The positive contribution of universities to innovation reflects the wider literature on the role of collaboration for innovation (Love et al., 2011; Woerter and Roper, 2010; Rantisi, 2002). Numerous studies have demonstrated the value of collaboration with customers (Mansury and Love, 2008; Love and Mansury, 2007), suppliers (Smith and Tranfield, 2005; Takeishi, 2001), consultants etc. (Tether and Tajar, 2008) as part of firms' innovation activity. Collaboration may also have other advantages, for example, in sharing risks, in accelerating or upgrading the quality of the innovations made and signalling the quality of firms' innovation activities (Powell, 1998). There is also increasing evidence that developing external collaborations involves organisational learning as firms' ability to structure and manage such relationships improves with experience (Love et al., 2014a,b). Two main learning mechanisms are envisaged in existing studies: the possibility that firms may become better at managing or structuring external collaboration; and, the possibility that experience may enhance firms' cognitive capacity to absorb external knowledge extending the number of useful collaborations (Laursen and Salter, 2006; Leiponen and Helfat, 2010).

Here, we consider: (a) whether learning from prior collaboration helps firms to collaborate with universities in developing new-to-the-market innovation; and, (b) whether prior collaboration contributes to

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¹ Clearly orientation- and transaction- related barriers are not mutually exclusive, with differences in institutional logic, particularly around publishing and/or the protection of knowledge manifest in conflicts around IP.

the market success of such partnerships in terms of innovative sales. We focus particularly on new-to-the-market innovation as this creates the potential to generate competitive advantage for the innovating firm and has other advantages in terms of helping the first movers in any technology, to learn rapidly about new markets, and build brand loyalty among customers (Ulhoi, 2012; Markides, 2006; Kopel and Löffler, 2008)². University collaboration may also be particularly important in generating new-to-the-market innovations which involve greater risks associated with technological complexity than new-to-the-firm innovation (Keizer and Halman, 2007; Roper et al., 2008; Cabrales et al., 2008; Astebro and Michela, 2005).

Our analysis makes use of the panel data element of the UK Innovation Survey (UKIS) covering the 2004–2012 period. Utilising that element of the UKIS panel which provides consecutive observations for individual firms allows us to identify causal links between learning processes, collaboration with university partners and innovation.³ We make three main contributions to the existing literature. First, we examine firms' choice of new-to-the-market innovation strategy, identifying the role of university collaboration as part of firms' innovation decision. Second, we are able to provide evidence on how firms' learning influences the nature and success of future collaboration. And, finally, we connect university-business collaboration to new-to-the-market innovation, an effect which proves both robust and of significant scale.

The remainder of the paper is structured as follows. Section 2 defines the two worlds of university and business innovation and outlines our view of new-to-the-market innovation strategy and firms' collaboration decisions. Section 3 profiles our data and empirical methodology. Section 4 deals with empirical results and Section 5 discusses the implications. Our results do not resolve the two-worlds paradox but do suggest that firms with prior experience of innovation collaboration may be better able to resolve at least part of the paradox when it arises.

2. Conceptual setting and hypotheses

2.1. Two-worlds of innovation

For firms, innovation is most typically an opportunity or market-driven activity, shaped by their technical and financial resources and their profit and growth ambitions. Yet, the characteristics of innovation activity may vary across sectors with science-based firms focusing to a greater extent on basic research while less science-intensive firms are more concerned with overcoming technical problems and introducing incremental innovation. Further, the size of the firm may also shape innovation strategy with small firms, for example, more likely to undertake innovation in an ad hoc and episodic manner, as a consequence of resource constraints (Corradini et al., 2016). In each case, undertaking R&D and innovation is, for firms, a means to an end; an investment which is undertaken only when it will generate value for the firm's stakeholders and customers.

For universities, however, knowledge creation is a core activity, an end in itself. Here, the objectives of undertaking research, and in some cases innovation, are more complex, driven by universities' multiple stakeholders and interest groups (Jarzabkowski, 2005). Researchers' curiosity may play a part in determining universities' investment priorities, but priorities may also be shaped by the requirements of

funders, performance agreements, metrics or rankings (Hewitt-Dundas and Roper, 2018). Moreover, there is considerable heterogeneity within the university sector reflected in institutional differences in strategic priorities and support for university-business linkages and knowledge transfer (Hewitt-Dundas, 2012). For example, Hewitt-Dundas (2012) found that research-intensive universities in the UK undertook significantly more collaborative and contract research with firms than less research-intensive universities where activity was concentrated more on professional development activities.

The contrasting organisational objectives and incentive structures of universities and firms, compounded by extensive heterogeneity across both types of organisations, make it difficult to achieve the strategic alignment required for successful collaboration. Reviews of research on barriers to knowledge transfer between universities and firms reinforce the characterization of 'two-worlds'. De Wit-de Vries et al. (2018) based on a systematic literature review of the barriers to knowledge transfer emphasise cognitive and institutional differences which create 'orientation-related' barriers to collaboration (Bruneel et al., 2010). Cognitive differences related to differences in university and firm knowledge bases may also create barriers to effective collaboration (De Wit-de Vries et al., 2018). In addition, the culture of universities and businesses also vary, evidenced in differences in social behaviours, norms, beliefs, languages and opinions all of which make collaboration more difficult (De Wit-de Vries et al., 2018).

One area where institutional barriers to university-business collaboration exist is in the value and ownership of intellectual property (IP), which further accentuates differences between universities and businesses objectives for research and innovation. For firms, proprietary knowledge represents a potentially valuable commercial asset which they might seek to control using either strategic or formal IP protection methods such as patents or trademarks. And, where knowledge is not defensible it may be seen by firms as having little commercial value, however useful (Holgersson, 2013). For universities, the traditional view was that new knowledge, particularly where its creation was publicly-funded, should be a public good. This prioritised the publication rather than the protection of research results. In more recent years, however, legislative and policy changes – particularly the 1980 Bayh-Dole Act in the USA and subsequent developments internationally – have encouraged entrepreneurial or innovating universities to adopt a more protectionist approach to the intellectual property they develop (Mowery et al., 2004). In particular, universities have seen the exploitation of IP through spin-outs or licensing as an additional revenue stream (Cesaroni and Piccaluga 2016)⁴. Universities appreciation of the commercial value of IP may have offsetting effects on the ease of forming university-business partnerships. On the positive side, where a firm and university have a common interest in appropriating any benefits from the IP generated from collaborative projects this may help align the partners' strategic interests. More challenging may be the issue of IP ownership, and who should bear the costs of registering and defending any IP. This may lead to an increase in transaction and monitoring costs as R&D collaboration agreements become more complex, costly and time-consuming to develop.

Even where these orientation barriers can be overcome a range of transactional barriers may still stand in the way of R&D or innovation cooperation between the two-worlds of universities and firms (Bruneel et al., 2010). For firms, and particularly smaller companies, flexibility and market responsiveness are central to sustained competitiveness (Vossen, 1998). Universities typically operate to different timescales, shaped not by market needs but by institutional and bureaucratic

² A key issue for innovators in any market place, however, is their ability to sustain their position of market leadership. In some sectors – biotechnology or engineering – this may involve formal strategies such as patenting to protect intellectual property; in other sectors more strategic approaches may be adopted such as frequent changes or upgrades to product or service design. Aggressive pricing also provides a way in which market leaders may protect a position of technological leadership (Ulhoi, 2012).

³ See Hewitt-Dundas and Roper (2018) for a recent overview of the UK university sector.

⁴ For example, it is reported that spin-outs from the University of Oxford raised £1.9 billion in external investment between 2011 and 2018 and in August 2018 Ziylo, a life sciences spin-out business established by a University of Bristol PhD student was acquired in a deal worth £623 million (The Times, 2018, 45).

routines reflecting academic calendars and commitments, meeting schedules and the requirements of financial accountability (Perkmann et al., 2013; Galan-Muros and Plewa, 2016). Universities are characterised as being hierarchical, inflexible organisational structures (Galan-Muros and Plewa, 2016) evident in a culture of ‘decision paralysis’ (Eppler and Mengis, 2004). These differences in operational practices may limit universities’ ability both to develop and effectively operate partnerships within time-scales which are acceptable to firms.

Practical difficulties may also arise in partnership formation. Universities are often large and complex organisations posing significant challenges for firms, particular smaller firms, in seeing universities as appropriate and accessible innovation partners and identifying appropriate individuals to work with. Similarly, universities may have a poor understanding of the technology needs of potential business partners. Initiatives such as technology transfer offices may help to overcome these access issues by acting as intermediaries or boundary spanners, as well as providing support in structuring partnership agreements (Calcagnini and Favaretto, 2016; Comacchio et al., 2012). Innovation partners which play a bridging role such as consultants or other business service providers may also help overcome such access issues. Furthermore, policy initiatives such as Innovation Vouchers empower firms to approach potential university partners and provide an incentive for university academics to engage with smaller firms (Sala et al., 2016)⁵.

2.2. Learning to collaborate for innovation

A firm’s decision to invest in innovation depends on the expected post-innovation returns relative to the costs of innovation. The costs and returns of innovation will, in turn, depend both on the firm’s capabilities at the time of the decision to invest, and their capacity to match internal organizational structures to the needs of the innovation being pursued (Henderson, 1994; Stringer, 2000). For example, different kinds of innovation – i.e. incremental or radical, product or process – will induce different competitive effects, address different kinds of market opportunities, and require different knowledge inputs.

Where firms seek to introduce more radical or new-to-the-market innovations specific challenges arise (Kopel and Lofler, 2008; Markides, 2006; Roper et al., 2008; Cabrales et al., 2008; Astebro and Michela, 2005)⁶. As Keizer and Holman (2007, p. 30) suggest: ‘Radical innovation life cycles are longer, more unpredictable, have more stops and starts, are more context-dependent in that strategic considerations can accelerate, retard or terminate progress, and more often include cross-functional and or cross-unit teamwork. Incremental projects are more linear and predictable, with fewer resource uncertainties, including simpler collaboration relationships’⁷. To overcome and leverage the risks and challenges associated with radical or new-to-the-market innovation investment in internal discovery processes is required. However, as Stringer (2000) notes relying solely on internal R&D activities (and existing organizational routines) is unlikely to result in more radical innovation. Instead, collaboration with external organisations may provide a new source of ideas, knowledge and

complementary skills (Hottenrott and Lopes-Bento, 2016) as well as increasing firms’ ability to appropriate returns from innovation (Cassiman and Veugelers, 2006).

Such external links can be problematic, however, and prone to failure or early termination due to the difficulties of managing and coordinating collaborative research and allocating its returns (Sampson, 2005). For example, issues may arise in structuring appropriate contractual arrangements where multiple partners are involved, compounding the uncertainty of R&D project outcomes and the allocation of ownership of any new intellectual property (Ystrom et al., 2015). The difficulties associated with external knowledge sourcing for innovation have been extensively studied (Sampson, 2005), with Grimpe and Kaiser (2010) referring to this in terms of ‘gains and pains’. They articulate the pains of collaboration in terms of: the potential dilution of firms’ resources; a weakening of firms’ integrative capabilities; excessive demand on management capabilities in coordinating internal and external R&D efforts; difficulties in agreeing intellectual property rights; and, the costs of monitoring relationships (Audretsch, 2005; Ulset, 1996). The ‘pains’ of collaboration may be compounded in the context of university-business collaboration by differences in the organisational logics which shape the two-worlds of business and higher education (Bruneel et al., 2010).

Striking a balance between the pains and gains from R&D collaboration can be achieved through at least two mechanisms (Schildt et al., 2012). First, partner choice. Where collaborating partners have similar knowledge bases, e.g. overlaps in technological (specific) knowledge, then the potential for gains from collaboration increase. In such circumstances, knowledge generated externally is better aligned, or relevant, to internally generated knowledge and easier for the firm to absorb and adapt (Schildt et al., 2012). Careful partner choice therefore addresses Sampson’s (2005) observation that one of the main reasons why R&D relationships breakdown are clashes in corporate culture and partners’ objectives and expectations. The second mechanism through which the balance of pains and gains of R&D collaboration may be achieved is through experience, defined by Heimeriks and Duysters (2007, p. 29) in the context of alliances as ‘the lessons learned, as well as the know-how generated through a firm’s former alliances’. Prior experience of external knowledge sourcing may improve partner selection and management routines, reduce transaction costs, and enable firms to more effectively capture the knowledge flows from external collaborators thus, increasing the chances of successful innovation outcome. Firms may also develop a better understanding of the specific capabilities of different partner types and their potential contribution to either incremental or more radical innovation (Miotti and Sachwall, 2003). Further, firms will learn to discriminate between partners, such as universities, in determining the knowledge available and how it can be adapted and applied in their own context (Laursen and Salter, 2006).

In addition to prior experience of collaboration, firms’ collaboration capabilities may also depend on prior innovation experience. Where a firm has prior experience of undertaking new-to-the-market (NTM) innovation, either building purely on internal knowledge or collaboration, they are more likely to have an understanding of the associated knowledge requirements (Geroski et al., 1997). Through time, this suggests that firms which engage in persistent innovation and/or collaboration will learn both which types of collaboration are of most value, and how to maximise the payoffs from those relationships. This may be reflected in persistent – or recurrent – collaboration partnerships and, through time, the reduction of barriers associated with different institutional logics, the nurturing of inter-organisational trust (Gulati, 1995), the exchange of tacit and more fine-grained information and knowledge (Gilsing and Nooteboom, 2006), and the development of pathways to augment each partners’ knowledge base (Bruneel et al., 2010; Das and Teng, 2000; Belderbos et al., 2015).

Such a persistence of collaboration may be evident in collaborating with the same partner through recurring time periods (i.e. universities), or with a range of different partners (Laursen and Salter, 2006; Roper

⁵ Innovation voucher schemes typically provide small (c. 2-5,000 Euro) cash grants for smaller firms to access knowledge transfer services or intellectual property generated by universities or other knowledge providers. Vouchers can play a catalytic role helping firms to establish relationships with universities for the first time (OECD, 2010).

⁶ In this paper we follow the distinction between new-to-the-market and new-to-the-firm innovation which is adopted by the UK Innovation Survey (UKIS). New-to-the-market innovation is defined as ‘the introduction of a new or significantly improved product onto the firm’s market before any other competitors’. Incremental innovation is approached by new-to-the-firm innovation defined as ‘a good or service that was essentially the same as a good or service already available from competitors’.

⁷ See also Leifer et al. (2000).

et al., 2008). In other words, there is the potential for dynamic economies of scope as management teams learn from collaborative innovation partnerships in one period and apply that learning in subsequent periods.

2.3. Hypotheses

NTM innovation is expensive, risky and complex. Firms may therefore seek external collaborators who can augment their own internal knowledge structures and share the costs and risks of innovation (Fey and Birkinshaw, 2005; Nieto and Santamaria, 2007; Un et al., 2010). Potential collaborators differ, however, both in terms of the breadth and depth of knowledge they possess, but also in terms of their willingness to share that knowledge with prospective partners (Un et al., 2010). Because of such differences, firms' choice of innovation collaborators will depend on the type of R&D resources they seek to access, which, in turn, depends on their own knowledge profile (Miotti and Sachwald, 2003).

Notwithstanding evidence that external knowledge sourcing can make a significant positive contribution to firms' innovation performance (Oerlemans et al., 1998; Grant and Baden-Fuller, 2004), the effect may vary depending on the external partner (Lopez-Vega et al., 2016). In general, innovation collaboration is more common with supply chain partners – suppliers or customers – than with other organisations such as universities or consultants (Abreu et al., 2008). Here, orientation-related barriers are lower (Bruneel et al., 2010) and customers and suppliers represent 'local' knowledge partners where knowledge accessed builds on firms' existing resources (knowledge stocks) and capabilities (routines) (Lopez-Vega et al., 2016). In contrast, 'distant' search with partners such as universities is more difficult, requires new capabilities, and leads to knowledge which is further removed from the firm's current knowledge base but brings greater potential to lead to breakthrough innovation outcomes (Bingham and Spradlin, 2011; Lopez-Vega et al., 2016).

This suggests that a learning effect exists in external knowledge sourcing along at least two dimensions. First, through forming collaborations with 'local' knowledge sources, i.e. where cognitive distance is lower, firms develop knowledge sourcing capabilities and reduce orientation-related barriers with their external partners. This enhances not only the firm's knowledge stock but also their capability to collaborate with more 'distant' external partners. That is, 'interactional knowledge stores enable effective expansion of relationship types in the relationship portfolio, which in turn facilitate explorative and exploitative innovation simultaneously' (Fang et al., 2011, p. 746). Second, through external collaboration for innovation, firms' 'functional knowledge store' is enhanced with further collaborations building on this functional capability (Johnson et al., 2004; Fang et al., 2011). In other words, external collaboration with non-university partners, i.e. customers or suppliers, and/or consultants⁸ reduces orientation-related barriers to co-operation through enhancing both general knowledge of identifying, accessing, co-developing and absorbing external knowledge, as well as specific knowledge related to innovation and the identification of new technological and market opportunities. Some other types of non-university partner – particularly consultants or other business service providers – may also play a bridging role, helping firms to identify relevant university partners and help with introductions or brokering linkages (Bessant and Rush, 1995; Czarnitzki and Spielkamp, 2003). These arguments suggest:

Hypothesis 1: Learning to collaborate. Prior experience of external collaboration for innovation with non-university partners will increase the probability of subsequent collaboration with university partners.

⁸ Consultants have been identified to play an important boundary-spanning role as well as filling a managerial gap in articulating the potential innovation benefits from collaboration with other partners (Bessant and Rush, 1995).

Beyond the potential for learning arising from collaboration with non-university partners, learning also occurs through recurrent 'distant' collaborations. Bruneel et al. (2010) discuss this in terms of recurrent collaborations with universities helping to overcome orientation-related and transaction-related barriers to collaboration. Their findings support other research (Thune, 2011; Gomes et al., 2005; Hall, 2003; Van Dierdonck and Debackere, 1988) which suggests that, it is through repeated collaboration that routines are established on issues such as research targets, dissemination of results and timing of deliverables. These routines reduce attitudinal (orientation-related) barriers to collaboration for both business and university partners and may also have a – more limited – effect on reducing transaction-related barriers to collaboration, e.g. agreement on intellectual property (IP) issues.

Fang et al. (2011) conceptualise this learning effect as relationship-specific memory defined as the 'stored knowledge of collective insights, beliefs, routines, procedures and policies accumulated from interactions' which is shared between partner organizations (p. 744). In their study of high-tech manufacturing firms in Taiwan they found that the development of relationship-specific memory was fundamental in reducing cognitive distance between partners and the potential for cognitive failure. Recurrent collaboration therefore increases communication and coordination between partners and serves to overcome orientation-related barriers to collaboration such as attitudinal differences and potential conflicts of interest between partners. This suggests that prior collaboration⁹ with an external partner – and particularly a more 'distant' cognitive partner (Lopez-Vega et al., 2016) – will result in subsequent collaboration, therefore, in terms of university-business collaboration we anticipate that:

Hypothesis 2: Recurrent collaboration. Prior collaboration with universities for innovation will significantly increase the probability of subsequent collaboration with universities for innovation.

Essentially similar experiential learning effects may also arise from firms' prior experience of undertaking new-to-the-market innovation. These effects arise from the cumulative and path-dependent nature of innovation activity which builds on existing resources, capabilities and relationships. Empirical research on the persistence of innovation has, however, found that while product and (to a slightly lesser extent) process innovation activities persist from one period to the next, firms find it difficult to sustain high levels of innovation over time, with this being particularly difficult for smaller firms (Roper and Hewitt-Dundas, 2008; Cefis and Orsenigo, 2001). Sustaining an ability to introduce new-to-the-market innovations is likely to require firms to adopt a strategic approach to partner choice (Bengtsson et al., 2015). For example, Köhler et al. (2012) identify those partner types most strongly associated with success in introducing NTM innovation for a large group of European firms. Their findings suggest that 'science-driven search' with universities and research institutes and 'supplier-driven' search are most strongly associated with NTM innovation. Conversely, 'market-driven' search with customers is most strongly linked to, more imitative, new-to-the-firm innovation. This suggests that firms' innovation strategy – whether focused on NTM or incremental innovation – will influence their external knowledge search behaviour and partner choice (Hung and Chou, 2013; Wu and Shanley, 2009). In addition, firms' prior experience of having introduced NTM innovation may act as a signal to university partners of their capability to apply advanced technology in highly innovative ways (Penin, 2005; Nokkala et al., 2008). This leads to our third hypothesis:

H3: Prior NTM innovation. Prior experience of new-to-the-market innovation will increase the probability of innovation collaboration with universities.

⁹ In modelling terms prior experience from (non) university collaboration is approached with a lagged dependent variable and in this case a significant effect on concurrent university collaboration is expected.

Internal discovery processes and external collaborations with universities and other partners provide the knowledge inputs to the process of innovating. Universities and other public knowledge sources have, arguably, two specific advantages as innovation collaborators for the introduction of new-to-the-market innovation. First, NTM innovation typically requires frontier-edge knowledge which itself is likely to require significant R&D investments such as those made by universities¹⁰. Second, NTM innovation may create significant economic benefit increasing the potential threat from moral hazard associated with collaborative relationships. Universities and other public knowledge providers generally have little commercial incentive to cheat as well as robust (and sometimes bureaucratic) administration of intellectual property (Kaufmann and Todtling, 2001). In addition, notwithstanding the two-worlds differences in institutional logics and priorities between businesses and universities which may create tensions around project timelines, rewards and commercialisation (Dasgupta and David, 1994), co-patenting with Universities has been found to enhance market value and signal to the market the presence of novel technologies (Leten et al., 2013). This suggests our final hypothesis:

Hypothesis 4: From knowledge to innovation. Collaboration with universities will increase the probability of introducing new-to-the-market innovation.

3. Data and methods

3.1. UK higher education sector

The context for our analysis is the UK. The Higher Education sector in the UK comprises 162 institutions registered as being in receipt of public funding with 136 of these being members of Universities UK. Together these higher education institutions educate 2.32 million students of which approximately 76 per cent are undergraduate students. Estimated total income of these institutions was £34.7bn (2015–16) with 55 per cent of this attributable to teaching activities and 22.5 per cent attributable to research activities¹¹.

Over the past 20 years there has been a shift towards the marketisation of higher education in the UK as public funding for universities has declined alongside regulatory changes permitting the entry of new higher education providers. The UK White paper ‘The Future of Higher Education’ (2003) and the Higher Education Act (1 July 2004) introduced significant changes to investment in higher education and reinforced the commitment of the earlier 1997 Dearing Report (‘Higher Education in a Learning Society’) and the Lambert review of Business-University collaboration¹² (2003) to more closely align universities with the needs of businesses and the wider economy. Indeed, the UK Government’s Science and Innovation Investment Framework 2003–2014 (2004) commented that ‘Over the next ten years, it is critical that the levels of business engagement with the science base increase, to realise fully the economic potential of the outputs of our scientists and engineers to turn basic and strategic research into successful new products and services, and to engage more fully with business’. Indeed, UK universities reported a real terms increase of 79.8% in the value of collaborative research undertaken with business between 2003–04 (£698.9 m) and 2014–15 (£1257 m).¹³

¹⁰ Here, heterogeneity of the university sector is likely to be important with highly research-intensive universities more likely to produce frontier-edge knowledge than less research-intensive universities where the research focus is more applied (see Hewitt-Dundas, 2012).

¹¹ <http://www.universitiesuk.ac.uk/facts-and-stats/Pages/higher-education-data.aspx>

¹² http://www.eua.be/eua/jsp/en/upload/lambert_review_final_450.1151581102387.pdf

¹³ <https://webarchive.nationalarchives.gov.uk/20170712123726/http://www.hefce.ac.uk/ke/hebci/indicators/>

Although there has been a marked increase in reported university-business engagement, this has been unevenly distributed across the higher education sector. For example, Hewitt-Dundas (2012) considers how UK university’s research intensity is reflected in knowledge transfer activity. Academics in less research-intensive universities were found to generate only 10 per cent of the contract research income, 28 per cent of the collaborative research income and 69 per cent of the consultancy income generated by academics in research intensive universities. However, academics in less research-intensive universities generated almost twice (189 per cent) the average income from delivering courses to businesses and the community, compared to academics in research intensive universities. Other studies have also pointed to this heterogeneity in the university sector both in the UK and elsewhere¹⁴. For example, Haeussler and Colyvas (2011) in examining differences in the motives and attitudes of individual researchers engaging with industry find that, in addition to other factors, institutional and disciplinary characteristics strongly influence the personal motivations of researchers to undertake research collaborations. Further, Bishop et al. (2011) also found that firms derive different types of benefits from collaboration with different universities although the quality of the institution was important, for only a subset of the benefits from collaboration. Finally, Ding and Choi (2011) also identified the presence of heterogeneity in knowledge transfer activities, with academics from prestigious research universities more likely to serve on scientific boards. While there is agreement of the presence of heterogeneity across the university sector, this has predominantly been examined in terms of differences in universities knowledge exchange activity. While acknowledging this heterogeneity, in this paper our main focus is on how firms learn to collaborate with universities, thereby overcoming the two-worlds paradox and the effect of this collaboration on the probability of introducing new to the market innovation.

3.2. The UK innovation survey

Our analysis is based on the UK Innovation Surveys (UKIS) which cover the period 2004 to 2014. This survey is non-compulsory and is conducted every two years, resulting in a pooled cross section dataset comprising five waves of data. Questionnaires were sent by post using as a sampling frame the Interdepartmental Business Register, after stratifying for firm size (in terms of number of employees), region and industry sector. Achieved response rates range from 51.1 per cent in wave 7 (covering firms’ innovation activity over the period 2008–2010) to 58 per cent in wave 4 (covering 2002–2004)¹⁵. The UK Innovation Survey applies the definitions and type of questions defined in the OECD Oslo Manual (2005) and, for innovating firms, provides detailed information on the nature of firms’ innovation and their collaboration with universities and other partners¹⁶. The survey also provides information on a range of other firm-level characteristics which we use as control variables (see Annex 1 and Annex 2). Each wave consists of approximately fourteen thousand firms resulting in a pooled database of around seventy-five thousand observations. The UKIS is a sample survey which results in an extremely unbalanced dataset, nonetheless our theoretical framework dictates that our empirical analysis should have a dynamic element. Hence, in order to exploit as much information as possible we employed the conditional mixed process (Roodman, 2011) estimator in Stata 14 which allows us to use all available observations reaching a sample size of approximately 65,000 observations

¹⁴ For a review of Heterogeneity and University-Industry Relations, see special issue of Research Policy, Vol. 40, No. 1.

¹⁵ See: <https://www.gov.uk/government/collections/community-innovation-survey>

¹⁶ Filters included in the UKIS mean that questions on collaboration for innovation are only asked of firms which undertook some innovation in products or services, or processes in the period covered by the survey.

Table 1
Descriptive Statistics.

	Estimation sample N = 7580		Small firms N = 2891		Medium firms N = 2247		Large firms N = 2442	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
New to market innov (0/1)	0.390	0.488	0.371	0.483	0.404	0.491	0.402	0.490
Sales NTM products/services (%)	3.836	11.673	4.750	13.929	3.493	10.417	3.110	9.718
University Collaboration (0/1)	0.124	0.330	0.102	0.303	0.125	0.330	0.150	0.357
Consultancy Collab (0/1)	0.149	0.356	0.113	0.316	0.150	0.357	0.191	0.393
Customer Collaboration (0/1)	0.300	0.458	0.268	0.443	0.305	0.460	0.334	0.472
Supplier Collaboration (0/1)	0.276	0.447	0.231	0.421	0.278	0.448	0.328	0.470
Competitor Collaboration (0/1)	0.124	0.329	0.117	0.322	0.120	0.326	0.134	0.341
Employment (Log)	4.556	1.556	3.053	0.592	4.619	0.609	6.380	0.964
R&D investment (0/1)	0.475	0.499	0.445	0.497	0.496	0.500	0.489	0.500
R&D investment (Log)	1.850	2.568	1.237	1.855	1.998	2.524	2.430	3.122
Design (0/1)	0.334	0.472	0.295	0.456	0.336	0.472	0.380	0.485
Exporter (0/1)	0.453	0.498	0.407	0.491	0.491	0.500	0.471	0.499
Other Grads (No.)	11.434	19.258	11.323	20.241	11.300	18.835	11.701	18.432
Sci & Eng Grads (No.)	10.295	19.143	11.360	21.494	9.949	18.374	9.352	16.665
Publications (0/1)	0.099	0.299	0.086	0.280	0.102	0.302	0.113	0.316
Previous innovation barrier (0/1)	0.110	0.313	0.121	0.326	0.104	0.305	0.103	0.303
Market conditions barrier (0/1)	0.143	0.350	0.171	0.376	0.133	0.340	0.119	0.324
Other barriers (0/1)	0.086	0.280	0.092	0.289	0.079	0.270	0.085	0.278

Notes and sources: Estimation sample (after selection) comprises innovative firms which responded to two consecutive waves of the UK Innovation Survey. See also Annex 3.

for the full sample.

3.3. Dependent variables and collaboration measures

We use two different dependent variables to explore the role of learning from prior collaboration on the success of university-business collaborations in generating (a) new-to-the-market innovations and (b) related sales. In the UKIS respondents who indicated that they introduced either a new or significantly improved product or service were then asked to indicate whether their ‘business introduced a new good or service to the market before competitors’. Based on firms’ responses we construct a binary variable which takes the value of 1 if the innovating firm has introduced a NTM innovation and 0 otherwise. 39 per cent of innovating firms indicated that they introduced a NTM product or service rather than a new-to-the-firm (NTF) product or service during the survey period (Table 1). This proportion varied very little between firm sizes (Table 1). Firms are also asked about the proportion of their sales derived from NTM innovation. This measure – standardly used in studies of firms’ innovation activity – provides an indication of the initial market success of firms’ NTM innovation activity. This measure averaged 3.8 per cent of sales for our estimation sample (Table 1).

In terms of university collaboration, our measure is derived from a question ‘did your business co-operate on any innovation activities with any of the following: universities or other higher education institutions (HEI)?’¹⁷ and takes the value of 1 if the firm reports a collaboration with a HEI and 0 otherwise. 12.4 per cent of innovating firms reported university collaboration over the 2002–12 period, with such cooperation significantly more likely for larger businesses (Table 1). Furthermore, prior experience from non-university collaboration, university collaboration and NTM innovation, is captured using lagged variables from the former UKIS wave (i.e. t-1). Hypothesis 2 anticipates, for example, a significant effect of prior university collaboration on the probability to collaborate with a University partner in the current

period (t).

Nonetheless, filters included in the UKIS mean that information on collaboration for innovation are only asked of firms which undertook some innovation in products or services, or processes in the period covered by the survey. This means that our analysis is restricted to innovating firms and that at least part of the positive correlation between collaboration and innovation could be by construction rather by variation between collaborating and non-collaborating companies¹⁸. To address this issue and account for the potential selectivity bias of the relationship between NTM innovation (success) and university collaboration, our third dependent variable reflects firm’s decision (not) to engage in innovation either product, service, process and/or organisation.

3.4. Econometric strategy

We estimate the following trivariate dynamic and recursive model which simultaneously estimates the joint probability of introducing new-to-the-market innovation ($NTMI_t$) and the likelihood of collaborating with a university (UNI_COOP_t) conditional on firms’ decision to engage in innovation activities ($INNODEC_t$)¹⁹.

More specifically,

$$NTMI_{it} = \alpha_0 + \alpha_1 UNI_COOP_{it-1}^{NTMI} + \alpha_2 OTH_COOP_{it-1}^{NTMI} + \alpha_3 FLC_{it}^{NTMI} + \varepsilon_{1t} \quad (1)$$

$$UNI_COOP_{it} = \beta_0 + \beta_1 NTMI_{it-1}^{UNI-COOP} + \beta_2 UNI_COOP_{it-1}^{UNI-COOP} + \beta_3 OTH_COOP_{it-1}^{UNI-COOP} + \beta_4 FLC_{it}^{UNI-COOP} + \varepsilon_{2t} \quad (2)$$

$$INNODEC_{it} = \gamma_0 + \gamma_{2t} BARRIERS_{it}^{INNODEC} + \gamma_{3t} FLC_{it}^{INNODEC} + \varepsilon_{3t} \quad (3)$$

$$\varepsilon_{1t}, \varepsilon_{2t}, \varepsilon_{3t} \sim N_3[(0,0,0), (1,1,1, \rho)]$$

where OTH_COOP_t denotes collaboration with other innovation partners, $BARRIERS_{it}$ are a series of variables relating to innovation barriers, and the three FLC_t terms are sets of firm and sector level controls specific to each model. The variables $BARRIERS_{it}$ are used to identify

¹⁷ In the UKIS firms were asked to indicate separately whether university (and other) collaborators were regional, national or international. Here, we aggregate these variables into a single binary variable which takes value 1 if a firm collaborated with a university regardless of location. In addition, due to the structure of the UKIS questionnaire there is no way of disentangling whether previous collaboration with a particular university partner implies a current collaboration with the same or another university partner.

¹⁸ We owe this comment to an anonymous reviewer.

¹⁹ We implement this model using the Heckman selection model capability in CMP. See Roodman, (2011), p.191 for illustrative syntax.

the selection model and do appear in Eqs. (1) and (2). ε_{1t} , ε_{2t} and ε_{3t} are random errors assumed to be independently and identically distributed as a trivariate normal with unitary variance and correlation coefficient equal to $\rho = \text{corr}(\varepsilon_{1t}, \varepsilon_{2t}, \varepsilon_{3t})$. Eq. (1) here is the standard innovation production function relating innovation outputs in the current period to knowledge inputs from investment within the firm or external collaborations (Leiponen and Byma, 2009; Leiponen, 2012). Eq. (2) reflects the effects of learning and expected returns on the probability of collaborating with a university (Love et al., 2014a,b). Eq. (3) is the selection equation through which we correct for any potential innovation decision selectivity bias (Roodman, 2011). Models (1) and (2) are estimated conditional on Eq. (3), i.e. excluding firms not undertaking any innovation.

In principle, we could allow for a feedback loop in our system of equations, i.e. a direct effect of the probability to introduce new-to-the-market innovation on the likelihood of collaborating with a university; however, a coherency problem arises. [Gourieroux et al. \(1980\)](#) and [Maddala \(1983\)](#) prove this model is inconsistent, and prior parameter restrictions are needed in order to be logically consistent. Our assertion is instead that the decision to cooperate with a university in the current period is determined by firms' previous experience of collaboration and from its past innovation activity ([Rosenberg, 1976](#)). This restricts our post-selection sample to those innovators who responded to consecutive survey waves. Annex 3 compares this group with all innovators.

The correlation coefficient between the three error terms (ε_{1t} , ε_{2t} , ε_{3t}) accounts for all possible omitted or unobservable factors that drive both the probability to introduce new-to-the-market innovation and the likelihood of collaborating with a university conditional on the decision to engage in innovation activities. The significance of $\hat{\rho}$ represents a 'proof of the goodness of this approach'. In other words, if $\hat{\rho}$ is not significantly different from zero, the error terms are not correlated and the model can be consistently estimated using two univariate probit models. On the other hand, if $\hat{\rho}$ is significantly different from zero, the estimates of two separate probit models are inconsistent and joint estimation is required. Finally, in all models we allow for clustering of errors due to the non-independence of observations within the same firm capturing at least part of any unobserved heterogeneity.

Where our new-to-the-market innovation indicator is binary, it might be appropriate to estimate the three equations using simple probit estimators. However, as we suggest in Hypothesis 1, the decision to cooperate with a university and introduce new-to-the-market innovation may be inter-related with elements of firms' innovation strategy. Potential endogeneity suggests that univariate probit models might produce biased and inconsistent results and we therefore use a modelling strategy which simultaneously estimates the probability of introducing new-to-the-market innovation (NTMI_{it}), and collaborating with a university (UNI_COOP_{it}) conditional on the likelihood of undertaking innovation (INNODEC_{it}). Where our new-to-the-market innovation indicator is the percentage of sales, bounded at zero, we use a tobit estimator again allowing for potential endogeneity of university collaboration. Both models are implemented using the selection model syntax in the CMP module in Stata 14 (see [Roodman, 2011, p. 191](#)).

3.5. Explanatory variables

Variables reflecting collaboration with other types of innovation partners are defined in a similar way to that for university collaboration ([Table 1](#) and Annex 1), with the most common collaborators being suppliers (28 per cent of firms) and customers (30 per cent of firms). In the innovation production function (Eq. (1)) we include firms' current decision to collaborate with a university and other types of partners as explanatory variables. However, the decision to collaborate with a University is potentially dependent on previous learning effects from past collaboration with a university and other partners as well as previous new-to-the-market innovation. In Eq. (2) we therefore incorporate the lagged decisions to collaborate with universities and

other types of partners as well as previous new-to-the-market innovation as explanatory variables. Both the decision to introduce a new-to-the-market innovation and collaborate with a university are conditional on the decision to invest in innovation and for this reason we employed the corresponding selection equation.

We have also included in our analysis a set of control variables which previous studies have linked to dimensions of innovation activity. In the innovation production function, we include firms' internal investments in R&D which we anticipate will be positively associated with the probability that a firm will introduce new-to-the-market innovation. Second, we include another binary variable reflecting firms' innovation related investments in design. Furthermore, we have included a dummy variable for the importance of standards in firms' innovation activities and, here, we also expect a positive effect on new-to-the-market innovation. In order to capture any market scale effects we have included a binary variable indicating whether or not a firm was selling in export markets. Previous studies have linked exporting and innovative activity through both competition and learning effects ([Love and Roper, 2015](#)).

Turning to the control variables included in the collaboration model (Eq. (2)), we include two variables reflecting the strength of firms' human resources – the percentage of the workforce which are graduates in science and engineering and the percentage of all other graduates ([Freel, 2005](#); [Hewitt-Dundas, 2006](#)). In addition, we include a dummy variable reflecting the importance of publications as a knowledge source in firms' innovation activities. For both controls we expect a positive effect on the decision to collaborate with a university.

On the right-hand side of the selection equation we include three binary indicators of whether firms encountered financial, knowledge and demand constraints in their decision to invest in innovation ([Pellegrino and Savona, 2017](#)) as well as a binary indicator of whether or not the firm has an in-house R&D capability ([Love and Roper, 2001](#); [Griffith et al., 2003](#)). The three constraint variables identify the selection equation as they are not used elsewhere in the model. Finally, in all equations we control for firm size by incorporating the (log) employment in the estimated models to reflect the scale of plants' resources, and we allow for sectoral and temporal heterogeneity by including sectoral dummies at the 2-digit level and wave dummies.

4. Empirical results

In [Table 2](#) we report dynamic probit models of the innovation strategy decision to develop NTM innovation in collaboration with a university allowing for selection (Eqs. 1 and 2). Both dynamic models include sectoral and time period dummy variables (not reported). We find evidence of significant residual correlations suggesting the simultaneity of firms' innovation and collaboration decisions. This finding is consistent for both our full-sample estimation and for small, medium and larger firms ([Table 2](#)). The implication is that for firms of all sizes, strategy choices relating to the type of innovation firms introduce are strongly inter-linked with their decision to collaborate with universities ([Monjon and Waelbroeck, 2003](#); [Belderbos et al., 2004](#)).

Our first two hypotheses relate to potential learning effects. Does collaboration with other types of organisations (e.g. suppliers, customers) for innovation in a previous period help firms overcome the two-worlds paradox (Hypothesis 1)? And, does having prior collaboration with a university mean that firms are more or less likely to continue some similar relationship (Hypothesis 2)? For our full sample we find little evidence of learning effects from prior collaboration with customers, suppliers or competitors ([Table 2](#), part 2). There is, however, evidence that previous collaboration with consultants increases the probability of university collaboration. The scale of each of these effects can be identified from [Table 3](#) which reports the marginal values derived from the models reported in [Table 2](#). In [Table 3](#), which relates to the determinants of university collaboration, the coefficient on prior consultancy implies that on average a firm is around 3.4 percentage

Table 2

The innovation strategy decision: The probability of introducing new-to-the-market products and university cooperation conditional on the decision to innovate.

	Full (N = 64,749)	Small (N = 32,855)	Medium (N = 18,320)	Large (N = 13,574)
1. New to the market innovation (0/1)				
University Collaboration (0/1)	0.250*** (0.020)	0.245*** (0.038)	0.280*** (0.060)	0.252*** (0.080)
Consultancy Collab (0/1)	0.015 (0.017)	0.041 (0.048)	−0.074* (0.042)	0.129*** (0.038)
Customer Collaboration (0/1)	0.228*** (0.033)	0.187*** (0.022)	0.274*** (0.047)	0.197*** (0.021)
Supplier Collaboration (0/1)	−0.022 (0.024)	−0.054* (0.029)	0.080** (0.038)	−0.079 (0.055)
Competitor Collaboration (0/1)	0.043 (0.034)	0.070 (0.054)	0.003 (0.036)	0.072 (0.056)
Employment (Log)	−0.068*** (0.010)	−0.102*** (0.019)	−0.052 (0.039)	0.062*** (0.022)
R&D investment (Log)	0.110*** (0.003)	0.157*** (0.011)	0.120*** (0.006)	0.000 (0.000)
Design (0/1)	0.271*** (0.015)	0.265*** (0.015)	0.248*** (0.014)	0.302*** (0.039)
Exporter (0/1)	0.167*** (0.020)	0.152*** (0.044)	0.163*** (0.033)	0.216*** (0.036)
Constant term	−0.319*** (0.060)	−0.275*** (0.061)	0.044 (0.248)	−0.158 (0.115)
2. University collaboration decision (0/1)				
New to market t-1, (0/1)	0.162** (0.074)	0.120 (0.122)	0.285** (0.120)	0.133 (0.099)
University collaboration t-1 (0/1)	1.172*** (0.034)	1.224*** (0.090)	1.065*** (0.104)	1.202*** (0.061)
Consultancy collaboration t-1 (0/1)	0.185*** (0.067)	−0.093 (0.096)	0.201** (0.096)	0.342*** (0.115)
Customer collaboration t-1 (0/1)	0.019 (0.030)	0.188*** (0.056)	−0.042 (0.065)	−0.011 (0.088)
Supplier collaboration t-1 (0/1)	−0.037 (0.063)	−0.061 (0.045)	0.086 (0.109)	−0.138* (0.086)
Competitor collaboration t-1 (0/1)	−0.063 (0.098)	−0.175 (0.150)	−0.042 (0.098)	0.009 (0.122)
Employment (Log)	0.063*** (0.014)	0.103** (0.041)	0.022 (0.053)	0.129*** (0.045)
Other Grads (No.)	0.001 (0.002)	0.003 (0.002)	0.001 (0.003)	−0.001 (0.003)
Sci & Eng Grads (No.)	0.009*** (0.001)	0.008*** (0.001)	0.009*** (0.002)	0.011*** (0.002)
Publications (0/1)	0.475*** (0.074)	0.590*** (0.091)	0.578*** (0.053)	0.306*** (0.103)
Constant term	−1.408*** (0.095)	−1.438*** (0.104)	−1.266*** (0.246)	−2.050*** (0.198)
3. Innovation decision (Selection, 0/1)				
Employment (Log)	0.019 (0.017)	0.032*** (0.010)	0.005 (0.008)	0.030 (0.020)
R&D investment (0/1)	1.212*** (0.030)	1.277*** (0.053)	1.198*** (0.013)	1.051*** (0.023)
Product innovation barrier (0/1)	−0.638*** (0.059)	−0.538*** (0.070)	−0.711*** (0.074)	−0.842*** (0.046)
Market conditions barrier (0/1)	−0.899*** (0.043)	−0.822*** (0.042)	−0.988*** (0.062)	−1.004*** (0.040)
Other barriers (0/1)	−0.661*** (0.067)	−0.575*** (0.060)	−0.730*** (0.100)	−0.864*** (0.069)
Constant term	−0.283*** (0.104)	−0.287*** (0.084)	0.003 (0.069)	−1.262*** (0.159)
/atanhrho_12	−0.067* (0.035)	−0.061 (0.076)	−0.172*** (0.046)	0.018 (0.066)
/atanhrho_13	−0.143*** (0.038)	−0.119*** (0.038)	−0.070 (0.059)	−0.455*** (0.112)
/atanhrho_23	−0.325*** (0.050)	−0.273*** (0.066)	−0.381*** (0.081)	−0.243*** (0.089)
Number of observations	64,749	32,855	18,320	13,574
LogL	155,639	−20,981	−12,507	−10,336
Chi2	−43,627	38,001	10,144	143,185

Notes and sources: UK Innovation Survey, waves 4–9 pooled sample. All models include wave and industry dummies. Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 3

Marginal effects of the decision to collaborate with a university conditional on self-selecting to innovation.

	Full (1)	Small (2)	Medium (3)	Large (4)
New to market t-1, (0/1)	0.030** (0.014)	0.020 (0.021)	0.052** (0.021)	0.028 (0.020)
University collaboration t-1 (0/1)	0.217*** (0.006)	0.205*** (0.008)	0.195*** (0.021)	0.252*** (0.010)
Consultancy collaboration t-1 (0/1)	0.034*** (0.012)	−0.016 (0.017)	0.037** (0.018)	0.072*** (0.025)
Customer collaboration t-1 (0/1)	0.004 (0.006)	0.031*** (0.008)	−0.008 (0.012)	−0.002 (0.018)
Supplier collaboration t-1 (0/1)	−0.007 (0.012)	−0.010 (0.007)	0.016 (0.020)	−0.029* (0.017)
Competitor collaboration t-1 (0/1)	−0.012 (0.018)	−0.029 (0.024)	−0.008 (0.018)	0.002 (0.026)
Employment (Log)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.001)
Other Grads (No.)	0.002*** (0.000)	0.001*** (0.000)	0.002*** (0.000)	0.002*** (0.000)
Publications (0/1)	0.088*** (0.014)	0.099*** (0.018)	0.106*** (0.009)	0.064*** (0.020)
Number of observations	6,267	2,296	2,021	2,108

Notes and sources: UK Innovation Survey, waves 4–9 pooled sample. All models include wave and industry dummies. Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

points more likely to be collaborating with a university if it previously collaborated with consultants (Table 3).

Those learning effects which prove statistically significant differ between firm sizebands (Table 2), although as with the consultancy effect for all firms, the effect sizes remain relatively small (Table 3). For small firms (with less than 50 employees), prior collaboration with customers increases the probability of university collaboration by around 3.1 percentage points, while prior supplier and competitor collaboration have small negative and insignificant effects on the probability of university collaboration (Table 3). For medium and large firms, prior collaboration with consultants proves significant, increasing the probability of university collaboration by 3.7–7.2 percentage points. Other potential learning effects from prior collaboration prove insignificant (Table 3). Overall, while we do find some evidence of statistically significant learning effects from prior collaboration, these effects are relatively small in magnitude.

Larger effects, which are consistent across firm size bands, are evident from prior collaboration with universities. On average, past collaboration with a university means that firms are 22 percentage points more likely to engage in university collaboration in the next (three year) period covered by the innovation survey (Table 3). One significant caveat is worth noting here, however, linked to the nature of the UK Innovation Survey data: We cannot identify whether in periods t-1 and t firms' collaboration is with the same university or different universities. What we are therefore observing is a generalised persistence effect in collaboration with universities, i.e. firms which collaborate with universities in the past are more likely to be collaborating with universities in the current period. It is also possible that this result be a consequence of collaborative projects between firms and universities which are longer than a single survey period (i.e. 3 years) or overlap survey periods and are therefore captured in two survey observations. This collaboration effect remains robust, however, even when we re-estimate the model using a two-wave lag, i.e. university collaboration taking place 2–5 years before the current period²⁰. Such positive and significant effects from

²⁰ To illustrate, our baseline models explain innovation in 2012 to 2014 using a single lag, i.e. prior collaboration during the 2010 to 2012 period. A two-wave lag relates to prior collaboration during the 2008 to 2010 period. Due to space limitations these empirical results are not presented here but are available upon request.

past university collaboration on the probability to collaborate in the current period indicates a strong persistence effect in university collaboration (Bellucci and Pennacchio, 2016).

Our third hypothesis relates to the relationship between undertaking NTM innovation in the previous period and subsequent university collaboration. Again, this effect proves positive for all firm sizebands, although significant only for all firms and medium-sized firms (Table 2). On average, undertaking prior NTM innovation increases the probability of current university collaboration by 3.0 percentage points over and above any effect from prior university collaboration (Table 3). Possible explanations for this positive effect depend on whether firms undertaking NTM innovation in the previous period were collaborating with a university. For firms undertaking NTM with university collaborators, it is likely that learning effects predominate as experience helps firms to understand the value of university collaboration. For firms undertaking NTM without a university partner a number of learning mechanisms are possible. First, it is possible that through undertaking NTM innovation, firms developed their absorptive capacity which made it easier to collaborate with universities in future (Enkel and Heil, 2014; Bellucci and Pennacchio, 2016). Second, the experience of undertaking NTM innovation without a university partner may have highlighted the potential value of university input to subsequent developments reflecting firms' own bounded knowledge-base, particularly where firms have substantial absorptive capacity (Belderbos et al., 2016). Finally, prior NTM innovation may be acting as a positive signal to potential university partners of firms' internal capabilities and therefore their attractiveness as a future partner (Comino and Graziano, 2015).

Our final hypothesis relates to the impact of university collaboration on NTM innovation itself. Here we anticipate, and find, a positive relationship, with university collaboration increasing the probability that a firm will develop NTM innovation rather than purely NTF innovation by 10.7 percentage points (Table 4). This effect is strongly significant and consistent across firm sizebands. It is also consistent with evidence from other studies which suggest the value of collaboration for more radical innovation (Zang et al., 2014), and the more specific value of university knowledge (Bellucci and Pennacchio, 2016).

A range of other control variables also prove important in determining the probability of NTM innovation (Tables 2 and 3). Design investment, exporting and in-house R&D are all positively associated with NTM innovation. Customer collaboration also proves important, increasing the probability of NTM innovation by 5.9–8.5 percentage points (Table 4). We find weaker evidence on the value of prior collaboration with consultants, and no significant supplier collaboration effect (Table 5).

Another standard measure of firms' innovation activity is provided by the share of revenues derived from innovative activity, i.e. from products or services newly introduced or significantly improved during the previous three years. This indicator can be interpreted as a short-term measure of innovation success – the ability of firms to generate sales from their innovation – but care is necessary in its interpretation as it remains a proportional indicator and therefore depends on not only on firms' innovation activity but the totality of their product/ service portfolio. This said, firms with a higher percentage of sales derived from innovative products/services, and particularly NTM products/services may be able to appropriate higher returns than firms with less innovative product/service portfolios. Our estimation suggests that university collaboration has a strong positive and significant link (7.7–8.7 percentage points) to the share of firms' sales derived from NTM products/services (Table 4). As with the probability of NTM innovation a number of other factors are positively and significantly related to NTM sales including design investment and exporting (Table 4).

5. Discussion and conclusions

Our analysis suggests three main empirical results which provide some new insight into the formation of university-business collaborations for innovation and the results of that collaboration. First, we do

Table 4

Marginal effects of the probability to introduce new-to-the-market innovations conditional on self-selecting to innovation.

	Full (1)	Small (2)	Medium (3)	Large (4)
University Collaboration (0/1)	0.080*** (0.005)	0.077*** (0.011)	0.087*** (0.016)	0.087*** (0.026)
Consultancy Collab (0/1)	0.005 (0.006)	0.013 (0.015)	−0.023* (0.014)	0.044*** (0.014)
Customer Collaboration (0/1)	0.073*** (0.010)	0.059*** (0.008)	0.085*** (0.013)	0.068*** (0.008)
Supplier Collaboration (0/1)	−0.007 (0.008)	−0.017* (0.009)	0.025** (0.012)	−0.027 (0.019)
Competitor Collaboration (0/1)	0.014 (0.011)	0.022 (0.017)	0.001 (0.011)	0.025 (0.019)
Employment (Log)	−0.021*** (0.003)	−0.031*** (0.006)	−0.016 (0.012)	0.024*** (0.008)
R&D investment (Log)	0.035*** (0.001)	0.049*** (0.003)	0.037*** (0.001)	0.000 (0.000)
Design (0/1)	0.086*** (0.005)	0.083*** (0.006)	0.077*** (0.004)	0.104*** (0.013)
Exporter (0/1)	0.053*** (0.007)	0.048*** (0.014)	0.051*** (0.009)	0.074*** (0.012)
Number of observations	6267	2296	2021	2108

Notes and sources: UK Innovation Survey, waves 4–9 pooled sample. All models include wave and industry dummies. Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

find evidence that firms' experience of prior collaborations with non-university partners increases the probability of subsequent university-collaboration. Specifically, medium and large firms have a higher probability of university collaboration if they have previously collaborated with consultants, while small firms seem to benefit from prior collaboration with customers. In both cases, effect sizes are relatively small, however, at 3–7 per cent. Second, prior university collaboration has a significantly stronger effect, increasing the probability of collaboration by 22 percentage points in the current period. Our other key results relate to the impact of university collaboration on the nature of firms' innovation outputs and suggest consistent benefits across firm sizebands. Collaboration with universities is also associated in our data with a 7.7–8.7 percentage points increase in the probability that a firm will introduce NTM rather than NTF innovation. This effect is broadly similar in size for firms in all sizebands. We also find a consistent positive and significant effect from university collaboration on the probability of firms' sales derived from NTM innovations.

In policy terms it is useful to think about our results in terms of a commercialisation pipeline with three phases: the formation of university-business collaborations; the outcome of those collaborations in generating NTM offerings (either products or services); and, the successful commercialisation of these NTM innovations. In terms of the formation of university-business collaborations for innovation, it is clear that larger firms are more active: 15 per cent of larger innovating firms (with more than 250 employees) were collaborating with universities compared to 12 per cent of small firms (Table 1). This is broadly similar to the pattern of collaboration with consultants: 19 per cent of large innovating firms were collaborating with consultants compared to 15 per cent of small innovating firms (Table 1). Lower levels of collaboration by small firms may relate to information failures relating to firms' perceptions of the benefits of university collaboration, the capabilities of university partners and their trustworthiness (Hewitt-Dundas and Roper, 2016; Bellucci and Pennacchio, 2016). If more small firms are to benefit from university collaboration for innovation this means over-coming any such information failures, and the 'two-worlds' paradox which may influence the success of small business-university collaborations. Our evidence suggests that prior collaboration with customers may help smaller firms increase collaboration with universities by around 3.4 percentage points, equivalent to the 'gap' in

Table 5

Sales of new-to-the-market innovation and university collaboration conditional on the decision to innovate.

	Full (1)	Small (2)	Medium (3)	Large (4)
1. Sales from NTM innovation (cont.)				
University Collaboration (0/1)	−0.492* (0.279)	−0.736*** (0.218)	−0.080 (0.917)	−1.156*** (0.247)
Consultancy Collab (0/1)	−0.137 (0.211)	−0.621** (0.284)	−0.274 (0.555)	0.169 (0.170)
Customer Collaboration (0/1)	1.485* (0.826)	1.955** (0.854)	0.180 (0.561)	0.528 (0.567)
Supplier Collaboration (0/1)	0.664*** (0.251)	1.022** (0.435)	0.421 (0.466)	0.191 (0.170)
Competitor Collaboration (0/1)	−0.242 (0.224)	0.282 (0.406)	−0.281*** (0.060)	0.302* (0.193)
Employment (Log)	−0.599 (0.555)	−0.895 (0.627)	−0.219 (0.264)	0.273* (0.160)
R&D investment (Log)	2.246*** (0.303)	3.750*** (0.337)	1.769*** (0.460)	1.224*** (0.140)
Design (0/1)	2.098** (1.040)	3.309*** (0.861)	0.467 (0.943)	0.749 (0.784)
Exporter (0/1)	0.660 (0.466)	0.890** (0.418)	0.114 (0.306)	0.021 (0.123)
Constant term	−8.946*** (1.924)	−9.923*** (2.151)	−4.723*** (0.787)	−8.993*** (1.842)
2. University collaboration decision (0/1)				
New to market t-1, (0/1)	0.002 (0.002)	0.002 (0.003)	0.002 (0.002)	0.002 (0.002)
University collaboration t-1 (0/1)	1.176*** (0.087)	1.313*** (0.074)	1.075*** (0.151)	1.175*** (0.075)
Consultancy collaboration t-1 (0/1)	0.213*** (0.055)	−0.111 (0.128)	0.216** (0.088)	0.409*** (0.092)
Customer collaboration t-1 (0/1)	0.042 (0.055)	0.187* (0.112)	−0.034 (0.071)	0.011 (0.167)
Supplier collaboration t-1 (0/1)	−0.044 (0.059)	−0.111 (0.132)	0.093 (0.085)	−0.150 (0.113)
Competitor collaboration t-1 (0/1)	−0.073 (0.056)	−0.273*** (0.090)	−0.051 (0.064)	0.054 (0.074)
Employment (Log)	0.050*** (0.014)	0.081** (0.039)	−0.051 (0.072)	0.064 (0.048)
Other Grads (No.)	0.001 (0.001)	0.002 (0.002)	−0.002 (0.003)	0.002 (0.002)
Sci & Eng Grads (No.)	0.010*** (0.001)	0.008*** (0.001)	0.010*** (0.001)	0.012*** (0.002)
Publications (0/1)	0.566*** (0.104)	0.667*** (0.070)	0.623*** (0.154)	0.477*** (0.164)
Constant term	−1.162*** (0.077)	−1.673*** (0.190)	−1.073*** (0.283)	−1.838*** (0.274)
3. Innovation decision (selection, 0/1)				
Employment (Log)	0.001 (0.021)	−0.007 (0.015)	−0.010 (0.012)	0.034*** (0.013)
R&D investment (0/1)	0.911*** (0.066)	1.023*** (0.078)	0.941*** (0.047)	0.809*** (0.040)
Product innovation barrier (0/1)	−0.179 (0.119)	−0.193*** (0.072)	−0.031 (0.075)	−0.152 (0.176)
Market conditions barrier (0/1)	−0.258 (0.168)	−0.301*** (0.105)	−0.070 (0.151)	−0.164 (0.172)
Other barriers (0/1)	−0.151 (0.119)	−0.184** (0.076)	−0.037 (0.079)	−0.084 (0.126)
Constant term	−0.438*** (0.115)	−0.402*** (0.106)	−0.252*** (0.044)	−1.285*** (0.097)
/lnsig_1	2.886*** (0.100)	3.045*** (0.098)	2.735*** (0.092)	2.609*** (0.041)
/atanhrho_12	−0.042 (0.051)	0.062 (0.050)	−0.072*** (0.018)	−0.079* (0.046)
/atanhrho_13	2.818*** (0.643)	2.598*** (0.342)	4.298** (2.054)	3.505*** (1.262)
/atanhrho_23	−0.039 (0.067)	0.048 (0.068)	−0.078*** (0.019)	−0.113 (0.081)
Obs	64,749	32,855	18,320	13,574
LogL	−104531	−49471.8	−30384.5	−23346.2
Chi2	5965.53	14323.99	90729.01	1978507

Notes and sources: UK Innovation Survey, waves 4–9 pooled sample. All models include wave and industry dummies. Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

rates of university collaboration between smaller and larger firms.

This is important as our results also reiterate the important contribution of universities to innovation, and the particular role which universities play for firms whose strategies focus on NTM innovation (Laursen and Salter, 2004). For these firms, university knowledge may provide the impetus for radical product or service development and the associated first mover advantages (Kopel and Löffler, 2008; Xin et al., 2010). More broadly, our results suggest the potential role of universities in stimulating NTM innovation, and the potential for related creative destruction processes with both their positive and negative connotations.

Our analysis provides some new insight into the role of learning effects and university collaboration in the commercialisation pipeline for new-to-the-market innovations. Four significant limitations are evident, however. First, in our current analysis we focus on university collaboration as a single entity. Previous studies have suggested, however, that collaboration with local or national universities may yield rather different outcomes to collaborating with international universities (Hewitt-Dundas et al., 2017). It is also worth noting that our analysis focuses on the UK university sector which has developed along rather different lines to those in other EU countries in recent years. In particular, the marketisation of the university sector has been more extensive in the UK than in some other EU countries with potential implications for university-business collaboration (Hewitt-Dundas and Roper, 2018). Second, here, to isolate learning from specific types of prior collaboration, we treat collaboration mechanisms as independent both from each other and firms' internal capabilities such as R&D. Other studies of collaboration have suggested potential complementary or substitute relationships between internal capabilities and external co-operation, and between alternative external collaborations (e.g. Cassiman and Veugelers, 2006). Typically, such studies have been cross-sectional, rather than the dynamic analysis reported here (although see Hagedoorn and Wang, 2012). Combining potential dynamic or learning effects such as those examined here with an analysis of complementarity or substitutability between firms' different knowledge sources would be a useful extension of the current analysis (Roper and Hewitt-Dundas, 2015). Third, our analysis here is cross-sectoral and, for the moment we simply control for sectoral contrasts in our analysis. Exploring these sectoral contrasts in more detail may provide further insight into the variety of commercialisation pipelines and suggest a more defined set of policy priorities. In particular, it may be useful to explore how firms' in different sectors and different sizebands connect with research-intensive and less research-intensive universities and examine the benefits they derive. This is not possible with our current dataset, however, and would require information on specific university partnerships beyond that included in the UK innovation survey. Finally, it is important to note that we focus on one specific mechanism – university collaboration – which may drive firms' innovation. Other mechanisms such as local knowledge spillovers (Roper et al., 2017) or informal knowledge sharing (Grimpe and Hussinger, 2013) may also be important either as complementary or substitute knowledge sources. Future analysis which adopts a more holistic view of the sources of knowledge which drive innovation would be a useful extension.

Conflict of interest declaration

We have no conflict of interest in respect of this paper.

Acknowledgements

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which may not exactly reproduce National Statistics aggregates. This research was supported by Economic and Social Research Council (ESRC) grant number ES/K006614/1. We are grateful for valuable comments from the editor and three insightful reviewers.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.respol.2019.01.016>.

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