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ERC Research Paper No 57

February 2017

www.enterpriseresearch.ac.uk

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ABSTRACT

UK government reports have emphasised the potential role of universities in driving localised economic development. There may be a utility-accessibility trade-off, however, between the accessibility of local university knowledge and its 'fit' with the specific needs of local firms. Here, using data from UK Innovation Surveys (UKIS) covering the period 2004 to 2012, we examine this trade-off and how it differs for firms of different sizes. Our analysis suggests four main empirical results. First, we find support for the predicted inverted-U shape relationship between the distance between collaborators and the innovation benefits. Second, we find evidence, in accord with the utility/accessibility trade-off, that local university collaboration benefits only small and medium firms. Third, we find that learning effects from previous collaborations with customers, suppliers etc. increase the probability of collaborative activity. Fourth, we find strong evidence of the persistence of university collaborations. Our results re-affirm the evidence from other studies of the value of university collaboration and suggest the value of policy action to address market failures which arise in the formation of university-small business collaborations.

ACKNOWLEDGEMENTS

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CONTENTS

1. INTRODUCTION

University-business collaboration has attracted significant attention from both researchers and policy makers interested in maximising the economic value of public knowledge investments. In the UK, a series of government reports has emphasised the importance of effective university-business collaboration, and the potential role of universities in driving localised economic development (Etzkowitz and Leydesdorff 2000). Proximity, it is argued, facilitates the exchange of tacit and complex knowledge through personal interaction and shared knowledge and experiences. In this context, the proximity of universities and other external knowledge sources plays a defining role in shaping firms' external knowledge sourcing strategies (Boschma, 2005), i.e. local knowledge sources may be easier and more cost-effective to access. However, in any particular location the range of knowledge available from universities or other knowledge sources may be limited (Guilani 2007; Leiponen and Helfat 2010). This may mean that a firm's search for knowledge which is appropriate for their specific needs becomes inter-regional or international, and requires collaboration with less easily accessible partners[1]. The implication is that firms' collaborative relationships with universities will be characterised by a *utility-accessibility trade-off* reflecting the utility or value of knowledge available from local and more distant collaborators and the relative accessibility of those partners. The utility or value of knowledge available from local collaborators may be limited by the number of local universities, their specific areas of expertise, or level of engagement with local firms. Individual firms' existing in-house knowledge may also increase or decrease the perceived utility of locally available knowledge.

The utility-accessibility trade-off is likely to work differently for firms with different resource profiles and knowledge requirements. Larger firms with a stronger internal resource base and greater absorptive capacity may be better able to take advantage of university collaborations to access tacit and

[1] The relevant literature has approximated this type of knowledge as explorative and/or emerging (Laursen 2012; Hohberger, 2014).

complex knowledge (Powell et al. 1996; Almeida et al. 2002; Inkpen 2002; Grant and Baden-Fuller, 2004). Larger firms may also be in a position to manage and successfully exploit more numerous collaborative relationships, potentially spanning multiple geographic levels. Small firms, on the other hand, may have more to gain from collaboration, but because of their limited internal resources may have more limited knowledge search and absorption capabilities (Vahter et al., 2014). As a result, more distant knowledge sources may be of greater utility but be less accessible, to smaller firms with implications for the utility-accessibility trade-off.

Recent analyses of how firms access external knowledge have emphasised the dynamic nature of knowledge search and learning processes (Vahter et al. 2014; Balland et al. 2015; Hewitt-Dundas et al. 2017). Our analysis here contributes to the growing literature on the dynamics of knowledge search and how this influences the geography of collaborative innovation. We make three main contributions; first, we introduce the idea of a utility-accessibility trade-off as a general framework within which the spatial context of collaboration, and its implications for the costs and benefits of collaboration can be considered. Secondly, we test the predictions of the utility-accessibility framework for local, national and international university-business collaborations for innovation for small, medium and large firms. Thirdly, we examine the dynamic interaction of proximity and collaboration with universities and their effects on firms' ability to introduce new-to-the-market innovations.

The remainder of the paper is organised as follows; in the next section we present our theoretical framework and the corresponding hypotheses. Section 3 is presents information about our dataset and empirical strategy. Section 4 presents estimation results while section 5 concludes.

2. CONCEPTUAL FOUNDATIONS

Knowledge acquired externally can make a significant contribution to firms' innovation outputs (Brunswicker and Vanhaverbeke 2015; Spithoven, Vanhaverbeke, and Roijakkers 2013; Parida, Westerberg, and Frishammar

2012). Firms may collaborate to augment or complement their own internal knowledge stocks (Roper and Hewitt-Dundas 2015), or to share the costs and risks of innovation (Astebro and Michela 2005). Where new technologies are risky, or the market prospects for an innovation are highly uncertain, firms may place higher value on working with collaborators who are seen as trustworthy and capable of providing frontier-edge knowledge (Laursen 2012). Collaboration with trusted public research organisations, such as universities, fulfils both criteria (Fabrizio 2009).

University-business collaborations for innovation may also have a particular, explorative, character which emphasises the development and sharing of tacit knowledge, and also the value of intensive face-to-face contacts between collaborators (Breschi and Lissonni 2001). Spillovers from universities themselves, or from such collaborations, are likely to share similar characteristics and may therefore be geographically bounded, or at least, that there may be limits to the geographical distribution of such spillovers (Storper and Venables 2004). Early evidence of the potential for such localised knowledge spillovers was provided by Jaffe (1989), with (Anselin, Varga and Acs 1997) providing more specific US evidence which suggested that knowledge created within 75 miles of any metropolitan area had significant localised innovation effects[2]. Geographical proximity may therefore shape firms' ability to access relevant university knowledge (Jaffe 1989; Anselin et al. 1997; Bode 2004; Autant-Bernard and LeSage 2011; Kang and Dall'erba 2016), with accessibility decreasing as distance increases (Figure 1).

Geographical co-location of a firm with a University or public research organisation is neither necessary or sufficient, however, to ensure that knowledge is transmitted between actors(Giulani 2007; Balland et al. 2015). Local collaboration will only provide access to a limited pool of knowledge,

[2] More recent studies for Germany Bode (Bode 2004), France (Autant-Bernard and LeSage 2011) and the US (Kang and Dall'erba 2016), however, suggest the existence of both regional and inter-regional spillovers, with the latter study suggesting that the inter-regional spillovers from academic research are stronger than those from private R&D.

leading to the potential for local lock-in, and a need to seek useful knowledge elsewhere (Boschma 2005; Dolfsma and Leydesdorff 2009). More extensive, geographically dispersed, knowledge search will increase the number of potential collaborators which a firm can consider, and therefore the probability that a firm will identify knowledge which is useful and complementary to its own internal knowledge-base (Love et al. 2014). The probability of identifying useful external knowledge will therefore increase as firms shift beyond purely local knowledge search (Figure 1). However, the greater the distance between actors, the more difficult it is to transfer newly created knowledge that is mostly tacit, ensure effective co-ordination and avoid potential issues of trust and cultural conflict which may reduce the benefits of collaboration (Hamel 1991; Simonin 1997; Rao and Schmidt 1998; Doney et al. 1998; Zaheer and George 2004). This suggests a trade-off between more easily accessible local knowledge, which may be of limited value to the firm, and more distant, less accessible and more costly, knowledge which is of greater value (Figure 1). This utility/accessibility trade-off suggests there may be an optimal level of geographical proximity between a firm and its university collaborators (Boschma 2005; Boschma and Frenken 2010; Broekel and Boschma 2012) which balances the utility of local and more distantly available knowledge with the greater search, assimilation and co-ordination costs of working with more distant university partners (Figure 1). This leads to our first hypothesis:

Hypothesis 1: The utility/accessibility trade off

Trade-offs between the accessibility and utility of external knowledge imply and inverted-U shape relationship between distance and the benefits of university collaboration.

Organisational capabilities and aspirations will also shape the nature of the utility/accessibility trade-off. For example, Laursen et al. (2011) suggest firms' propensity to collaborate with a local university will be influenced by both physical distance and the research quality of the university. The optimal level of geographical proximity may therefore depend on firms' openness to their external environment as well as their capacity to manage transaction,

search and co-ordination costs (Fontana et al. 2006). These capabilities may be very different in firms of different sizes. On one hand, small firms which operate in niche markets may have more limited internal resources (Vossen 1998) and absorptive capacity and may find it difficult to implement extensive knowledge search strategies and identify more distant university collaborators (Beise and Stahl 1999; Hewitt-Dundas 2006). Conversely, larger firms with greater absorptive capacity will be better able to exploit more geographically dispersed external knowledge. For small firms this means that, at any given proximity to a partner, the probability of being able to access knowledge will be lower than the average (Figure 2a). By contrast, larger firms with greater internal resources and greater absorptive capacity may be better able to access external knowledge (Figure 2b). However, the more limited internal resources of small firms may also mean that external knowledge is of more value to smaller companies. Vahter et al. (2014), for example, demonstrate that small firms derive greater innovation benefits from any given number of external collaborations than larger firms. This suggests that the probability of small firms obtaining useful knowledge from a university at any given distance is *greater* than that for large firms (Figure 2a), with the converse being true for larger businesses (Figure 2b). These combinations of effects suggest our second and third hypotheses:

Hypothesis 2: Local knowledge and smaller firms

Lower accessibility and higher utility will mean that local university knowledge sources are of greater innovation benefit to smaller firms.

Hypothesis 3: Distant knowledge and larger firms

Greater accessibility and lower utility will mean that more distant university knowledge sources are of greater benefit to larger firms.

Recent evidence suggests that the benefits of external collaboration for innovation may have a strong dynamic element (Love et al. 2014, 2014a). Firms, learning from prior collaborations, may develop new knowledge routines, and acquire new competences which benefit their ability to innovate. Improved partner selection and management routines, for

example, may reduce transaction and coordination costs, and enable firms to more effectively capture the knowledge flows from distant collaborators (Miotti and Sachwall 2003). Through time, firms which engage in collaboration will also learn both which types of collaboration are of most value, and how to maximise the payoffs from those relationships. This may be reflected in more persistent partnerships and, through time, the build-up of trust (Gulati 1995), the exchange of tacit and more fine-grained information and knowledge (Gilsing and Noteboom 2006), and the closer integration of internal and collaborative innovation routines (Das and Teng 2000; Belderbos et al. 2016). and, in this context, studies have again emphasised the role of proximity. In terms of the utility-accessibility trade-off, the potential for learning from prior collaboration implies a shift of both the utility and accessibility curves to the right (Figure 1), and therefore a potential increase in the distance at which the optimal benefit from collaboration may occur. This suggests our final hypothesis:

Hypothesis 4: Learning effects

Learning effects resulting from prior collaboration will increase the innovation benefits of collaboration with more distant university partners.

3. DATA AND METHODS

3.1 The UK Innovation Survey

Our analysis is based on the UK Innovation Surveys (UKIS) which covers the period 2004 to 2012. This survey is non-compulsory, and is conducted every two years. Questionnaires are sent by post using a sampling frame derived from the Interdepartmental Business Register and stratifying for firm size (in terms of number of employees), region and industry sector. Achieved response rates range from 51 per cent in Wave 8 (covering firms' innovation activity over the period 2010-2012) to 58 per cent in Wave 4 (covering 2002-

2004)[3]. 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 partners[4]. The survey also provides on a range of other firm-level characteristics which we use as control variables. Each UKIS wave consists of approximately 14,000 observations although the panel structure of the dataset is extremely unbalanced. For our analysis we require information on firms' collaboration with universities – which is only available for firms engaging in some innovation activity – and also data on firms which responded to two successive waves of the UKIS to allow us to capture potential learning effects. Applying these restrictions results in a pooled data set containing around 24,000 observations.

3.2. Dependent variables

UKIS respondents who indicated that they introduced either new or significantly improved products or services during a three year period were then asked to indicate whether this was introduced 'to the market before competitors'. Such new-to-the-market products and/or services have the potential for disruption because they may undermine the competences and complementary assets of incumbent firms (Markides 2006). Based on firms' responses we constructed a binary variable - $NTMI_t$ - which takes the value of 1 if the innovating firm has introduced a new-to-the-market innovation and 0 otherwise. Around 39.5 per cent of innovating firms indicating that they introduced a new-to-the-market product or service in the sample period (Table 1).

Besides the type of collaboration partner UKIS respondents have been also asked to indicate the location of their innovation partners using a three-way (regional, national or inter-national) categorisation. We use this data to construct three binary variables to represent the geographical profile of firms'

[3] See: https://www.gov.uk/government/collections/community-innovation-survey
[4] 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.

university collaboration. Specifically, $UNICOLLAB\_REG_t$ indicates whether firms were collaborating with regional universities (i.e. within 100 miles of the firm's location) and $UNICOLLAB\_NAT_t$ and, $UNICOLLAB\_INT_t$ indicate whether firms were collaborating with a national University (i.e. within the UK but more than 100 miles away of the firm's location) and international universities, respectively[5].

3.3. Econometric Strategy

Our hypotheses emphasise the potential for university collaboration to influence firms' new-to-the-market innovation. However, the decision to collaborate with a universities will depend on the utility accessibility trade-off (Hypothesis 1), firm size (Hypotheses 2 and 3) and firms' prior collaboration (Hypothesis 4). Our empirical strategy needs therefore to account for the potential interdependencies between the decision to introduce a new-to-the-market innovation, the location of university partners, and the potential simultaneity between these two decisions. In the presence of such interdependencies, univariate probit models may produce biased and inconsistent results. We therefore use a multivariate probit model to simultaneously estimate the probability of introducing new-to-the-market innovation – $NTMI_t$ - conditional on the likelihood of collaborating with a university at regional, national or international level. Hence, we estimate the following multivariate dynamic and recursive model:

$$NTMI_t^* = \alpha_0 + \alpha_1 UNICOLLAB\_REG_t + \alpha_2 UNICOLLAB\_NAT_t + \alpha_3 UNICOLLAB\_INT_t + \alpha_4 OTHCOLLAB\_REG_t + \alpha_5 OTHCOLLAB\_NAT_t + \alpha_6 OTHCOLLAB\_INT_t + \alpha_7 FLC_t + \varepsilon_{1t} \quad (1)$$

$$UNICOLLAB\_REG_t = \beta_0 + \beta_1 NTMI_{t-1} + \beta_2 UNICOLLAB\_REG_{t-1} + \beta_3 OTHCOLLAB\_REG_{t-1} + \beta_4 FLC_t + \varepsilon_{2t} \quad (2)$$

$$UNICOLLAB\_NAT_t = \gamma_0 + \gamma_1 NTMI_{t-1} + \gamma_2 UNICOLLAB\_NAT_{t-1} + \gamma_3 OTHCOLLAB\_NAT_{t-1} + \gamma_4 FLC_t + \varepsilon_{3t} \quad (3)$$

$$UNICOLLAB\_INT_t = \delta_0 + \gamma_1 NTMI_{t-1} + \delta_2 UNICOLLAB\_INT_{t-1} + \delta_3 OTHCOLLAB\_INT_{t-1} + \delta_4 FLC_t + \varepsilon_{4t} \quad (4)$$

[5] Note that while we know where firms' university partners are located our survey data provides no information on the absolute number of university (and other) collaborators with which firms are working.

$$\epsilon = (\varepsilon_{1t}, \varepsilon_{2t}, \varepsilon_{3t}, \varepsilon_{4t},)' \sim N(\mathbf{0}, \mathbf{\Sigma})$$

$$\Sigma = \begin{pmatrix} 1 & \rho & \rho & \rho \\ \rho & 1 & \rho & \rho \\ \rho & \rho & 1 & \rho \\ \rho & \rho & \rho & 1 \end{pmatrix}$$

where ε_{it}, *i* =1-4, are error terms distributed as multivariate normal, each with a mean of zero, and variance–covariance matrix Σ , where Σ has values of 1 on the leading diagonal and ρ are the error correlations. Furthermore, the $UNICOLLAB\_REG_{it}$, $UNICOLLAB\_NAT_{it}$, and $UNICOLLAB\_INT_{it}$ variables denote collaboration with other innovation partners at the corresponding level and FLC_t are a set of firm and sector level controls[6]. Equation (1) here is the standard innovation production function relating innovation outputs in the current period to innovation inputs from investment within the firm or external collaborations (Leiponen and Byma 2009; Leiponen 2012). Equations (2-4) reflect the effects of learning and expected returns on the probability of collaborating with a university (Love et al. 2014, 2014a).

Hypothesis 1 relates to the utility/accessibility trade-off and suggests an inverted-U shape relationship between the innovation benefits of collaboration and distance. This requires $\alpha_2 > \alpha_1$ and $\alpha_2 > \alpha_3$. Hypothesis 2 relates to the impact of small firm size and requires that α_2 – the parameter on local university collaboration – will be greater in sub-sample estimates relating to smaller firms. Conversely, Hypothesis 3 anticipates that α_4 – the coefficient on international university collaboration will be greater in sub-sample estimates for larger firms. Finally, Hypothesis 4 envisages learning from prior collaboration requiring β_2, $\beta_3 > 0$, γ_2 $\gamma_3 > 0$, and δ_2 $\delta_3 > 0$ for regional, national and international universities respectively. The correlation coefficient among the error terms ε_{it}, *i* =1-4, accounts for all possible omitted or unobservable factors that drive at the same time both the probability to

[6] In principle, we could allow for a feedback loop in our system of equations, i.e. simultaneity between the probability of introducing new-to-the-market innovation and the likelihood of collaborating with a university at the regional, national and international level. However, a coherency problem arises which Gouriroux et al. (1980) and Maddala (1983) show produces inconsistent results, and that prior parameter restrictions are needed in order to be logically consistent.

introduce new-to-the-market innovation and the likelihood of collaborating with a university. 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 is equivalent to the estimation of two univariate probit models. On the other hand, if $\hat{\rho}$ is significantly different from zero, the estimates of four separate probit models are inconsistent and a joint estimation is required. Finally, we correct for clustering of the standard errors which allows to take into account the non-independence of observations within the same firm, allowing to catch at least part of the unobserved heterogeneity.

3.4. Explanatory Variables

Variables reflecting collaboration with other types of innovation partners (e.g. customers, suppliers) are defined in a similar way to that for university collaboration (Table 1) with the most common collaborators being national suppliers (22.2 per cent of innovating firms) and national customers (25.2 per cent of innovating firms) (Table1). We should note that partnering with different types of collaborators may serve a two-fold purpose; on one hand, the diversity of innovation partners is considered an important determinant of the introduction of new-to-the-market innovation as it provides a variety of technological inputs which potentially complement firms' existing knowledge and skill endowments (Becker and Dietz 2004). On the other hand, the decision to collaborate with a university as part of firms' innovation activities may be determined by firms' history and experience of previous collaborations with university partners and other types of partners.

We therefore incorporate the lagged decisions to collaborate with a university and other types of partners as well as the previous success in introducing new-to-the-market innovations as explanatory variables of the current decision to collaborate with a university whether it be regional, national or international (equations 2-4).

We have also included in our analysis a set of control variables which previous studies have linked to dimensions of innovation activity examined

here. In the innovation production function (equation 1), we have included a binary indicator of whether or not a firm has an in-house R&D capability (Love and Roper 2001; Griffith et al. 2003) which we anticipate will be positively associated with the probability that a firm will introduce new-to-the-market innovation. Second, we include a binary variable reflecting firms' innovation related investments in design. Third, we also include a dummy variable for the importance of standardisation in firms' innovation activities which we also expect to have 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, and a Herfindahl index to approximate industrial concentration and firms' market power. Previous studies have linked exporting to innovative activity through both competition and learning effects (Love and Roper 2015).

Turning to the control variables included in the collaboration models (equations 2-4) we have included a variable reflecting the strength of firms' human resources – the percentage of the workforce which are graduates in science and engineering (Leiponen 2005; Freel 2005, Hewitt-Dundas 2006). In addition, we use 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. Finally, in both the innovation production function (equation 1) and the collaboration models (equations 2-4) we control for firm size by incorporating the (log) employment 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 in each equation.

4. EMPIRICAL RESULTS AND DISCUSSION

Our first Hypothesis relates to the effect of the utility/accessibility trade-off on innovation outputs, and suggests that co-operation with national universities should have the greatest innovation benefits. Table 3 reports multi-variate probit estimates of equation (1), modelling the effect of collaboration with regional, national and international universities on firms' ability to introduce new-to-the-market innovation. We find significant error

correlations between the different models suggesting the value of the multi-variate approach. Notably, however these correlations are stronger between the errors in the three university collaboration decision models (i.e. international, national, regional) than between the various types of university collaboration and innovation. The implication being that the decision about which type of university, or universities, to collaborate with are more strongly inter-connected than the innovation and collaboration decisions (Table 3). This is particularly evident for larger firms where the error correlations between the innovation production function (equation 1) and the collaboration models (equations 2-4) are insignificant (Table 3).

This suggests that decision processes regarding new-to-the-market innovation and university collaboration may be different in small and medium firms to those in larger companies. Previous studies have suggested that collaboration is related to the innovation decision process (Du, Love, and Roper 2007) but provide little insight into firm size differences. Our results here suggest that in small and medium firms the innovation and collaboration decisions appear closely related; in larger firms the decisions to introduce new-to-the-market innovation and collaborate are essentially independent. This may reflect the richness of firms' resource base, with new-to-the-market innovation actually requiring external collaboration in small and medium firms – and therefore necessitating the linking of the innovation and collaboration decisions (Lopez-Fernandez, Serrano-Bedia, and Gomez-Lopez 2016). Larger firms with stronger internal resources may, on the other hand, have more options about how they achieve new-to-the-market innovation with a choice between internalised or collaborative strategies. (Eiriz, Faria, and Barbosa 2013), for example, link their 'discovery' innovation strategy – involving radical innovation and potentially collaboration – with more mature and therefore potentially larger firms.

In our whole sample estimates (Model 1, Table 3) collaboration with both regional and national universities have positive and significant effects on the probability that firms will introduce new-to-the-market innovation. This is also reflected in the marginal effects, with collaboration with a national university increasing the probability of new-to-the-market innovation by 8.4 per cent on

average, and a regional university by 5.2 per cent (Table 4). In our full sample estimates, collaboration with international universities has no significant impact on the probability of introducing new-to-the-market innovation (Table 3). Our whole sample estimates therefore provide support for Hypothesis 1 and the utility-accessibility trade-off, with national universities also having the largest impact on innovation in each firm sizeband (Table 4).

Hypothesis 2 suggests that the utility-accessibility trade-off means that, relative to large firms, small firms will benefit more from collaboration with local universities. Our estimation supports this contention although the observed differences between small and medium firms are relatively small (Table 3). For small firms, collaboration with local universities increases the probability of new-to-the-market innovation by 7.1 per cent compared to 6.8 per cent in medium firms and 3.8 per cent in larger firms (Table 4). Small firms' collaboration with international universities suggests a negative (6.3 per cent) impact on the probability of new-to-the-market innovation (Table 4). This suggests the importance of the accessibility of knowledge for smaller firms and the potential for over-collaboration with international partners (although see Lew and Sinkovics 2013). Medium-sized firms seem able to overcome this issue obtaining innovation benefits from local, national and international university collaboration (Table 4). For larger firms – perhaps due to their stronger internal knowledge base - the benefits of collaboration with universities of each type are generally weaker, although again national universities provide the most significant innovation benefits (Table 4). This finding is consistent with Laursen et al. (2011) who found that UK firms tend to favour collaboration with national universities rather than those which are local or international. Overall, our results provide support for Hypothesis 2 but no real evidence for Hypothesis 3 that international collaborations are of greater benefit to larger firms.

Beyond their collaboration with universities, it is collaboration with customers which has the most consistently positive effect on firms' new-to-the-market innovation (Melton and Hartline 2015). As with universities, the strongest relationships are also evident here in terms of nationally-based customers rather than those based locally or internationally (Table 3). This suggests

that the type of utility-accessibility trade-off envisaged in Hypothesis 1 may extend beyond university collaboration. Collaborations with other partners have more diverse impacts, although it is notable that collaboration with international suppliers has significant beneficial effects for smaller firms (Table 3). Other factors also influence the probability that firms will undertake new-to-the-market innovation. Larger firms are more likely to introduce new-to-the-market innovations as do those with larger proportions of science and engineering graduates (Calcagnini and Favaretto 2016; Fores and Camison 2016).

Our final hypothesis suggests that learning effects from previous collaborations will increase the probability of collaborative activity with universities. Two types of learning effects are possible here: experience effects from collaboration with other types of partner (apart from universities) and experience effects from prior university collaboration. In terms of experience effects from collaboration with other types of partner, we find some evidence of learning effects in collaboration with international and national universities (Table 3). Learning effects seem less important as a determinant of firms' collaboration with regional universities (Table 3). More specifically, prior experience of working with international consultants generates significant positive learning effects in our full sample estimates (Model 1, Table 3) and for medium and large firms (Models 3 and 4, Table 3). Such collaboration may be helping firms to learn to overcome cultural or regulatory barriers to international collaboration, or helping them develop appropriate management routines (Ojanen and Hallikas 2009). Another possible explanation for this result is, however, that international consultants may be brokering contacts between UK firms and international universities (Bessant and Rush 1995; Prince 2012). Collaboration with national universities is also related to prior collaboration with national consultants, again perhaps reflecting learning or brokering effects, and prior collaboration with customers (Table 3). Prior customer collaboration may be generating dynamic economies of scope in the collaboration relationship but may also be helping firms to identify market opportunities, stimulating future innovation and collaboration. Finally, we find little evidence of significant learning effects in terms of firms' collaboration with regional universities (Table 3).

We also find strong experience or persistence effects from prior university collaboration for each type of university (Table 3). Two explanations are possible for this effect. First, it may simply be that in some instances collaborative projects between firms and universities are longer than a single survey period (3 years) and therefore the same project or projects is being captured in two survey observations. Second, it may be that firms experiencing university collaboration become aware of the benefits they derive, and continue that relationship in subsequent periods (Bellucci and Pennacchio 2016). From our data it is impossible to distinguish between these two possibilities. In previous studies using Spanish data, however, the vast majority of university-industry collaborations are of two years duration or less (Montoro-Sanchez, Mora-Valentin, and Guerras-Martin 2006)[7], suggesting the learning effect may be the primary explanation for the observed persistence in university collaboration.

Among the other factors which influence university collaboration – international, national and regional – the most consistent is the presence within the firm of larger groups of science and engineering graduates. This effect may reflect the ability of science trained graduates to effectively identify and assimilate external scientific knowledge – an absorptive capacity effect similar to that noted by Schmidt (2010) and Belderbos, Gilsing, and Suzuki (2016). Another complementary possibility is that science graduates may draw on their existing networks to support their employer's innovation activities (Calcagnini and Favaretto 2016).

5. CONCLUSIONS

Our main focus in this paper is firms' ability to introduce new-to-the-market innovations and how this is influenced by collaboration with universities at regional, national and international levels. We argue that the choice of university partners involves a utility/accessibility trade-off: local universities

[7] More specifically of 800 agreements analysed by Montoro-Sanchez et al. (2006, Table 5), 11 per cent of collaborations were of 0-12 months duration, 60.9 per cent were 13-24 months duration, 26.7 per cent were 25-36 months long and only 1.6 per cent exceeded 36 months.

are easy to access but their knowledge base may not ideally match the needs of local firms; the larger group of national and international universities may possess more relevant knowledge but at a greater access cost. This suggests an inverted-U shape trade-off relationship between distance between partners and the likely cost-benefit of collaboration. Firm size may change this trade-off. Small firms facing resource constraints may find it difficult to access distant knowledge but, at the same time, may derive greater benefit due to their weaker internal knowledge resources. Larger firms with stronger internal resources may be able to access more distant knowledge but benefit less from that knowledge.

Our empirical analysis, based on the UK Innovation Surveys (UKIS) covering the period 2004 to 2012, suggests four main empirical results. First, we find support for the inverted-U shape relationship predicted by the utility/accessibility trade-off between the distance between collaborators and the innovation benefits. Collaboration with a national university increases the probability of new-to-the-market innovation by 8.4 per cent on average, while collaboration with a regional university has a smaller 5.2 per cent effect. Second, we find evidence, in accord with the utility/accessibility trade-off, that local university collaboration benefits small and medium firms only, increasing the probability of new-to-the-market innovation by 6.8-7.1 per cent. Third, we find consistent evidence that learning effects from previous collaborations with customers, suppliers etc. increase the probability of collaborative activity. Fourth, we find strong evidence of the persistence of university collaborations, linked perhaps to firms' realisation of the value of such linkages.

Our results re-affirm the evidence from other studies of the value of university collaboration for new-to-the-market innovation, particularly to smaller companies. In terms of the utility/accessibility trade-off, an obvious policy implication is to improve small firms' accessibility to the national university network. For example, Interface in Scotland provides a single point of entry to Scotland's university network for small firms across a range of sectors. In 2015/16, Interface brokered links between 387 small firms and Scottish universities resulting in 172 collaborative projects (http://www.interface-

online.org.uk/). This type of initiative addresses two market failures which occur in the formulation of open innovation relationships: firms' lack of awareness of the potential benefits from university collaboration and their lack of knowledge of potential university partners (Hewitt-Dundas and Roper, 2016). Other research has also emphasised the potential value of initiatives to support smaller firms in the initial commercialisation of new-to-the-market innovations (Hewitt-Dundas et al. 2017).

Our analysis sheds new light on the benefits of university-business collaboration in the UK and the contrasting experience of firms of different sizes. While helpful our statistical analysis provides only limited information as to why the observed relationships occur, and how the utility/accessibility trade-off impacts on individual firms and individual decisions to collaborate and innovate. There would be considerable value in complementary case-level research which traces business-university collaborations from ideation through to consummation and completion. This type of detailed, longitudinal case-study has been used in studying academic entrepreneurship and spin-outs but similar narratives of university-business collaboration are rare (Lundquvist and Middleton, 2013). Ideally, such an analysis would focus on the drivers of the collaboration decision as well as helping to understand the factors which influence firms' mode of engagement with universities be it collaborative research or consultancy (Perkmann et al. 2013).

Table 1. Sample Descriptives

	No of Obs.	Mean	Std. Dev.
Probability of new-to-the-market innovation	23,616	0.395	0.489
Cooperation with university: regional	23,616	0.067	0.250
Cooperation with university: national	23,616	0.083	0.276
Cooperation with university: international	23,616	0.029	0.166
Cooperation with consultants: regional	23,616	0.065	0.246
Cooperation with consultants: national	23,616	0.119	0.324
Cooperation with consultants: international	23,616	0.045	0.208
Cooperation with customers: regional	23,616	0.145	0.352
Cooperation with customers: national	23,616	0.252	0.434
Cooperation with customers: international	23,616	0.131	0.338
Cooperation with suppliers: regional	23,616	0.110	0.313
Cooperation with suppliers: national	23,616	0.222	0.416
Cooperation with suppliers: international	23,616	0.129	0.335
Cooperation with competitors: regional	23,616	0.055	0.228
Cooperation with competitors: national	23,616	0.100	0.300
Cooperation with competitors: international	23,616	0.051	0.221
Employment (Log)	23,616	4.158	1.709
R&D spend (0/1)	23,616	0.642	0.480
Design spend (0/1)	23,616	0.411	0.492
Firm is exporting (0/1)	23,616	0.499	0.500
Herfindahl Index	23,616	0.009	0.033
Science and engineering grads (% workforce)	19,811	10.582	19.985
Publications important for innovation	23,616	0.102	0.303

Table 2: Correlation matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
(1) Probability of new-to-the-market innovation	-																						
(2) Cooperation with university: regional	0.1	-																					
(3) Cooperation with university: national	0.15	0.19	-																				
(4) Cooperation with university: international	0.08	0.15	0.3	-																			
(5) Cooperation with consultants: regional	0.06	0.4	0.12	0.09	-																		
(6) Cooperation with consultants: national	0.12	0.18	0.45	0.19	0.15	-																	
(7) Cooperation with consultants: international	0.10	0.13	0.26	0.48	0.14	0.28	-																
(8) Cooperation with customers: regional	0.06	0.25	0.09	0.08	0.3	0.12	0.09	-															
(9) Cooperation with customers: national	0.16	0.16	0.31	0.12	0.11	0.37	0.15	0.18	-														
(10) Cooperation with customers: international	0.18	0.2	0.31	0.28	0.14	0.27	0.34	0.2	0.36	-													
(11) Cooperation with suppliers: regional	0.04	0.24	0.08	0.07	0.34	0.13	0.09	0.44	0.15	0.13	-												
(12) Cooperation with suppliers: national	0.10	0.15	0.27	0.12	0.14	0.41	0.17	0.17	0.5	0.26	0.16	-											
(13) Cooperation with suppliers: international	0.14	0.16	0.25	0.24	0.12	0.27	0.35	0.12	0.3	0.45	0.15	0.29	-										
(14) Cooperation with competitors: regional	0.03	0.27	0.07	0.06	0.33	0.1	0.08	0.42	0.08	0.07	0.35	0.11	0.07	-									
(15) Cooperation with competitors: national	0.08	0.15	0.29	0.11	0.13	0.36	0.15	0.16	0.38	0.17	0.15	0.35	0.17	0.2	-								
(16) Cooperation with competitors: international	0.11	0.17	0.25	0.33	0.11	0.22	0.38	0.1	0.19	0.41	0.1	0.17	0.36	0.14	0.27	-							
(17) Employment (Log)	0.01	0.03	0.08	0.03	0.01	0.12	0.07	0.01	0.11	0.1	0.01	0.12	0.15	-0.02	0.06	0.08	-						
(18) R&D spend (0/1)	0.25	0.12	0.17	0.07	0.09	0.17	0.11	0.07	0.2	0.19	0.05	0.15	0.16	0.02	0.1	0.11	0.09	-					
(19) Design spend (0/1)	0.21	0.1	0.14	0.06	0.08	0.15	0.09	0.06	0.19	0.19	0.06	0.15	0.16	0.02	0.1	0.1	0.09	0.38	-				
(20) Firm is exporting (0/1)	0.18	0.07	0.16	0.1	0.02	0.12	0.13	-0.03	0.16	0.32	-0.02	0.09	0.23	-0.07	0.03	0.16	0.14	0.25	0.2	-			
(21) Herfindahl Index	-0.03	-0.01	-0.01	0.01	0.00	0.01	0.01	0.01	-0.01	-0.02	0.00	0.00	-0.01	0.01	0.01	-0.01	0.02	-0.02	-0.04	-0.05	-		
(22) Science and engineering grads (% workforce)	0.15	0.13	0.22	0.19	0.04	0.12	0.16	0.02	0.11	0.22	-0.01	0.06	0.13	0.01	0.06	0.14	-0.05	0.18	0.11	0.21	-0.01	-	
(23) Publications importance for innovation	0.07	0.11	0.17	0.11	0.07	0.15	0.13	0.1	0.13	0.14	0.08	0.1	0.1	0.08	0.11	0.11	0.02	0.09	0.08	0.07	0.01	0.16	-

Table 3: The probability of new-to-the-market innovation and university collaboration

	All firms	Small firms	Medium firms	Large firms
1. New-to-the-market innovation				
Cooperation with university: regional	0.189***	0.221**	0.212*	0.112
	(0.045)	(0.068)	(0.084)	(0.089)
Cooperation with university: national	0.256***	0.319***	0.258***	0.197*
	(0.042)	(0.070)	(0.078)	(0.075)
Cooperation with university: international	0.0325	-0.197*	0.257*	0.115
	(0.071)	(0.112)	(0.137)	(0.124)
Cooperation with consultants: regional		0.102	-0.156*	-0.027
	0.002 (0.042)	(0.063)	(0.081)	(0.083)
Cooperation with consultants: national		-0.012	-0.084	0.089
	0.001 (0.034)	(0.057)	(0.063)	(0.059)
Cooperation with consultants: international	0.109*	0.079	0.202*	0.082
	(0.053)	(0.095)	(0.098)	(0.088)
Cooperation with customers: regional	0.085*	0.084*	0.129*	0.044
	(0.031)	(0.045)	(0.059)	(0.063)
Cooperation with customers: national	0.212***	0.244***	0.180***	0.199***
	(0.026)	(0.041)	(0.048)	(0.051)
Cooperation with customers: international	0.158***	0.145*	0.180**	0.146*
	(0.034)	(0.054)	(0.061)	(0.063)
Cooperation with suppliers: regional	-0.071*	-0.075	-0.047	-0.096
	(0.034)	(0.049)	(0.066)	(0.070)
Cooperation with suppliers: national	-0.044*			-0.068
	(0.027)	-0.7* (0.041)	0.038 (0.049)	(0.052)
Cooperation with suppliers: international	0.109***	0.208***		0.076
	(0.032)	(0.055)	0.066 (0.057)	(0.056)
Cooperation with competitors: regional		-0.023		0.103
	0.005 (0.046)	(0.067)	-0.012 (0.090)	(0.095)
Cooperation with competitors: national		-0.014		-0.050
	0.004 (0.035)	(0.054)	0.085 (0.067)	(0.065)
Cooperation with competitors: international	0.088*	0.201*	-0.024	0.068
	(0.049)	(0.083)	(0.091)	(0.084)
Employment	-0.030***	-0.051**	-0.021	0.025*
	(0.006)	(0.017)	(0.019)	(0.013)
R&D spend	0.478***	0.470***	0.508***	0.442***
	(0.022)	(0.032)	(0.042)	(0.046)
Design spend	0.290***	0.317***	0.248***	0.283***
	(0.020)	(0.030)	(0.038)	(0.040)
Firm is exporting	0.200***	0.181***	0.223***	0.215***
	(0.021)	(0.030)	(0.042)	(0.043)
Herfindahl Index	-0.0693	0.927		-1.449
	(0.530)	(0.823)	0.331 (1.071)	(0.992)
Constant	-0.584***	-0.337*	-0.787***	-1.305***
	(0.104)	(0.144)	(0.203)	(0.286)

2. Cooperation with university: international				
Lagged probability of new-to-the-market innovation	0.112	0.162	0.164	0.0213
Lagged cooperation with university: international	1.168***	1.493***	0.940***	1.490***
Lagged cooperation with consultants: international	1.168***	1.493***	0.940***	1.490***
Lagged cooperation with customers: international	(0.133)	(0.250)	(0.267)	(0.240)
Lagged cooperation with suppliers: international	0.506***	-0.305	0.954***	0.589*
Lagged cooperation with competitors: regional	(0.136)	(0.300)	(0.247)	(0.227)
Employment	-0.0360	0.173	-0.288	-0.0128
Science and engineering grads	(0.112)	(0.191)	(0.231)	(0.201)
Publications importance		-0.0447		0.141
Constant	0.145 (0.110)	(0.232)	0.271 (0.195)	(0.187)
	-0.261*	-0.0616	-0.0669	-0.665*
	(0.153)	(0.301)	(0.281)	(0.263)
		-0.350*	-0.133	0.163*
	0.036 (0.025)	(0.150)	(0.123)	(0.075)
	0.014***	0.012***	0.013***	0.018***
	(0.002)	(0.003)	(0.004)	(0.003)
	0.196*	0.255	0.002	0.299*
	(0.106)	(0.183)	(0.226)	(0.175)
	-6.495	-5.258	-5.712	-7.445
	(547.7)	(823.9)	(496.7)	(957.1)
3. Cooperation with university: national				
Lagged probability of new-to-the-market innovation	0.217***	0.215*	0.358***	0.133
Lagged cooperation with university: national	(0.059)	(0.103)	(0.108)	(0.103)
Lagged cooperation with consultants: national	1.076***	1.139***	0.913***	1.173***
Lagged cooperation with customers: national	(0.076)	(0.147)	(0.141)	(0.123)
Lagged cooperation with suppliers: national	0.233**	0.0304	0.515***	0.186
Lagged cooperation with competitors: regional	(0.080)	(0.164)	(0.150)	(0.128)
Employment	0.128*	0.140		0.0541
Science and engineering grads	(0.072)	(0.134)	0.183 (0.129)	(0.122)
Publications important for innovation	-0.00990	-0.0802	-0.146	0.0677
	(0.073)	(0.137)	(0.135)	(0.122)
	0.0201	-0.00550	-0.246	0.161
	(0.089)	(0.176)	(0.174)	(0.138)
	0.0715***	0.00221	-0.0197	0.0948*
	(0.018)	(0.102)	(0.095)	(0.048)
	0.0142***	0.0115***	0.0168***	0.0165***
	(0.001)	(0.002)	(0.003)	(0.002)
	0.514***	0.439**	0.672***	0.511***
	(0.073)	(0.137)	(0.140)	(0.118)
	-2.406***	-6.520	-1.573*	-2.871***
	(0.299)	(10.837)	(0.564)	(0.776)

4. Cooperation with university: regional

Lagged probability of new-to-the-market innovation	0.229***	0.151	0.370***	0.168
	(0.060)	(0.103)	(0.112)	(0.105)
Lagged cooperation with university: regional	1.188***	1.249***	1.177***	1.213***
	(0.083)	(0.153)	(0.156)	(0.138)
Lagged cooperation with consultants: regional	0.149	0.0255	-0.125	0.340*
	(0.102)	(0.187)	(0.212)	(0.161)
Lagged cooperation with customers: regional	-0.111	0.124	-0.373*	-0.163
	(0.0949)	(0.164)	(0.197)	(0.157)
Lagged cooperation with suppliers: regional	0.020	-0.171	0.424*	-0.125
	(0.010)	(0.188)	(0.192)	(0.160)
Lagged cooperation with competitors: regional	0.033	-0.096	0.095	0.189
	(0.133)	(0.252)	(0.261)	(0.209)
Employment	0.0517*	0.118	0.0485	0.128*
	(0.019)	(0.102)	(0.095)	(0.051)
Science and engineering grads	0.009***	0.009***	0.007*	0.009***
	(0.001)	(0.002)	(0.003)	(0.003)
Publications important for innovation	0.537***	0.783***	0.534***	0.295*
	(0.077)	(0.133)	(0.150)	(0.128)
Constant	-2.742***	-2.463***	-6.898	-6.937
	(0.432)	(0.593)	(480.0)	(731.3)
Rho(12)	-0.0947	-0.0554	-0.243*	0.00634
Rho(13)	-0.124*	-0.0968	-0.249**	-0.0277
Rho(14)	-0.119*	-0.160*	-0.154*	-0.0371
Rho(23)	0.629***	0.762***	0.768***	0.372***
Rho(24)	0.308***	0.272*	0.232*	0.433***
Rho(34)	0.198***	0.0920	0.211*	0.308***
N	23616	10912	6629	6053
chi2	4077.3	1743.4	1190.5	1238.4
p	0.000	1.12e-303	7.13e-190	3.43e-201
bic	32150.8	14563.3	9558.8	9314.5

Notes and sources: UK Innovation Survey, waves 4-8 pooled sample. All models include wave and industry dummies. Standard errors in parentheses * p<0.05, ** p<0.01, *** p<0.001.

Table 4: Marginal effects on new-to-the-market innovation

	Full Sample	Small Firms	Medium Firms	Large Firms
Cooperation with regional university (0/1)	0.062*** (0.015)	0.071*** (0.022)	0.068*** (0.027)	0.038 (0.030)
Cooperation with national university (0/1)	0.084*** (0.014)	0.103*** (0.023)	0.082*** (0.025)	0.066*** (0.026)
Cooperation with international university (0/1)	0.011 (0.023)	-0.063* (0.036)	0.082* (0.044)	0.039 (0.042)
Cooperation with regional consultants (0/1)	0.001 (0.013)	0.033 (0.020)	-0.050** (0.026)	-0.009 (0.028)
Cooperation with national consultants (0/1)	0.000 (0.011)	-0.004 (0.018)	-0.027 (0.020)	0.030 (0.020)
Cooperation with international consultants (0/1)	0.036** (0.017)	0.026 (0.031)	0.064 (0.031)	0.028 (0.030)
Cooperation with regional customers (0/1)	0.028*** (0.010)	0.027* (0.015)	0.041** (0.019)	0.015 (0.021)
Cooperation with national customers (0/1)	0.069*** (0.009)	0.079*** (0.013)	0.058*** (0.015)	0.067*** (0.017)
Cooperation with international customers (0/1)	0.052*** (0.011)	0.047*** (0.017)	0.057*** (0.019)	0.050** (0.021)
Cooperation with regional suppliers (0/1)	-0.024** (0.011)	-0.024 (0.016)	-0.015 (0.021)	-0.032 (0.023)
Cooperation with national suppliers (0/1)	-0.014 (0.009)	-0.025* (0.013)	0.012 (0.016)	-0.023 (0.017)
Cooperation with international suppliers (0/1)	0.036** (0.011)	0.067*** (0.018)	0.021 (0.018)	0.025 (0.019)
Cooperation with regional competitors (0/1)	0.002 (0.015)	-0.008 (0.022)	-0.004 (0.029)	0.035 (0.032)
Cooperation with national competitors (0/1)	0.001 (0.012)	-0.005 (0.018)	0.027 (0.021)	-0.017 (0.022)
Cooperation with international competitors (0/1)	0.029 (0.016)	0.065 ** (0.027)	-0.008 (0.029)	0.023 (0.028)
Employment (Log)	-0.010*** (0.002)	-0.017*** (0.005)	-0.007 (0.006)	0.008** (0.004)
R&D spend (0/1)	0.157*** (0.007)	0.152*** (0.010)	0.162*** (0.013)	0.149*** (0.015)
Design spend (0/1)	0.095*** (0.007)	0.102*** (0.010)	0.079*** (0.012)	0.095*** (0.013)
Firm is exporting (0/1)	0.066*** (0.007)	0.058*** (0.010)	0.071*** (0.014)	0.073*** (0.014)
Herfindahl Index	-0.023 (0.174)	0.300 (0.265)	0.106 (0.341)	-0.488 (0.334)

Notes and sources: UK Innovation Survey, waves 4-8 pooled sample. All models include wave and industry dummies. Standard errors in parentheses * p<0.05, ** p<0.01, *** p<0.001.

Figure 1: The knowledge utility-accessibility trade-off

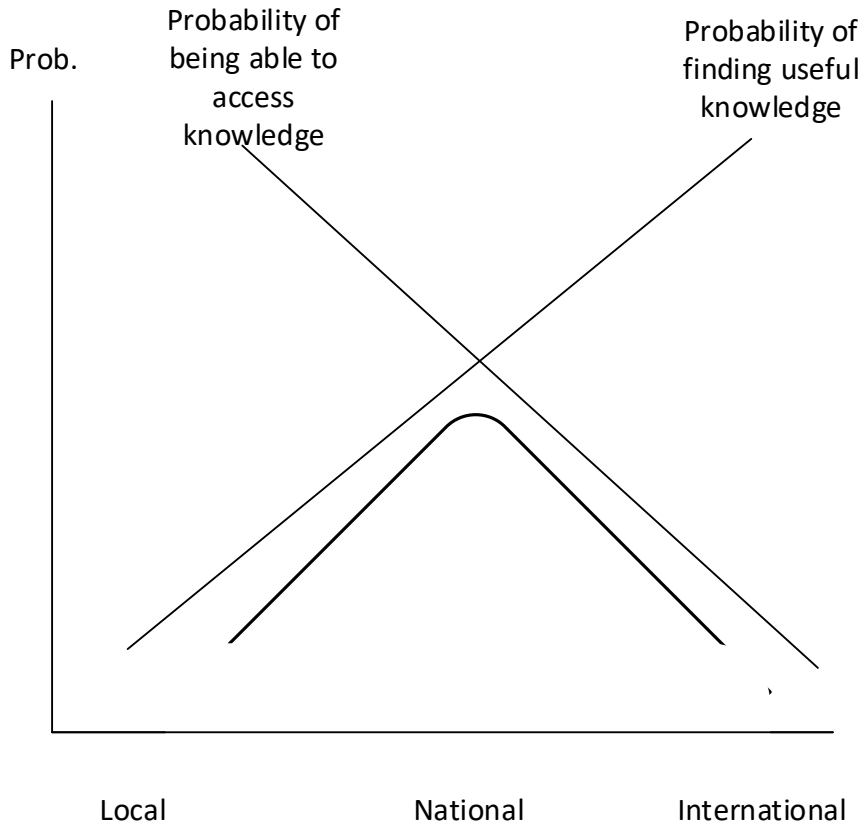
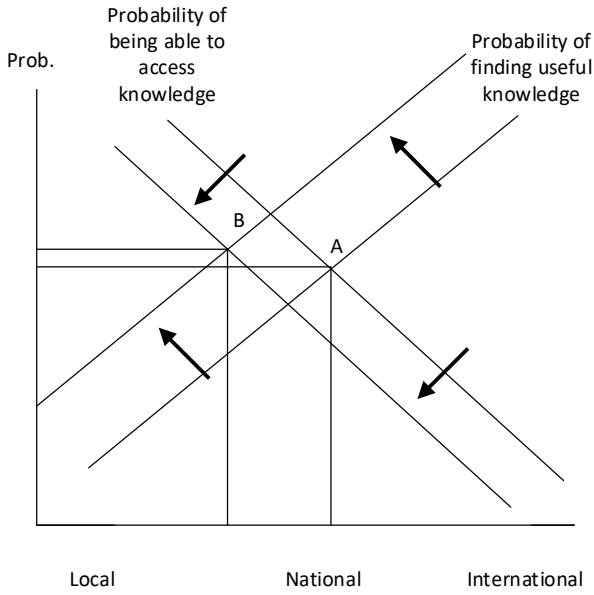
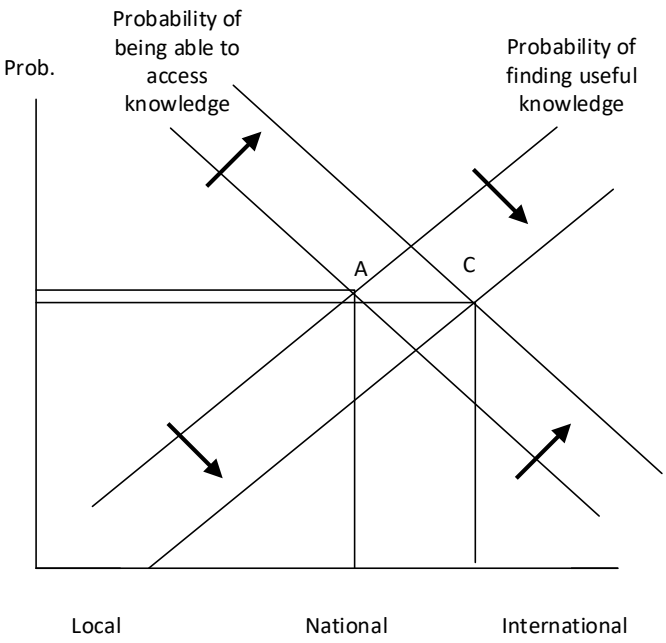


Figure 2: The knowledge utility-accessibility trade-off among smaller and larger firms

(a) Smaller firms



(b) Larger firms



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