Appropriability mechanisms for manufacturing and service firms: the contingencies of openness and knowledge intensity

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Abstract

Conventional wisdom argues that appropriating returns from innovation requires protection mechanisms. However, there will be limits to the effectiveness of formal and informal appropriability mechanisms for innovation performance. Their effectiveness will be contingent on the nature of the knowledge that firms are trying to protect and the openness of their innovation strategy (sharing knowledge while attempting to protect knowledge is known as the "paradox of openness"). Do these boundary conditions apply to both manufacturing and service firms equally though? Analysing data from the U.K. Community Innovation Survey, this study provides evidence for a continuum—from discrete product manufacturing firms, whose products rely heavily on codified, explicit knowledge and for which formal methods are strongly associated with innovation performance, to knowledge-intensive service firms, which tend to rely more on complex tacit knowledge and for which innovation is linked to informal, not formal, appropriability. The findings show that the paradox of openness is a limited problem for service firms. The benefits of collaboration for innovation performance outweigh any reduction in the effectiveness of appropriability. For manufacturers, the benefits of collaboration disappear with high formal appropriability, and thus discrete product manufacturers, contrary to conventional wisdom, may find it beneficial to reduce collaboration breadth and invest in informal appropriability mechanisms. Knowledge-intensive servitised manufacturers find formal methods effective but only with no or minimal collaboration.

Keywords: Appropriability; open innovation; innovation performance; service; manufacturing; knowledge-intensive firms

1. Introduction

Without the ability to generate profit from the commercialisation of innovations, firms have little incentive to engage in innovative activities (Teece, 1986). One way for firms to capture the benefits of innovation is to employ suitable appropriability mechanisms. Appropriability refers to the firm's ability to capture the value (e.g., rents, profits) from its innovations using mechanisms that help protect knowledge (Cohen et al., 2000; Pisano, 2006). However, Laursen and Salter (2005) suggest that there is a myopia of protectiveness and that the effectiveness of appropriability may be limited.

This paper argues that the differences between manufacturing and service firms, and the knowledge they are trying to protect, limit the relative effectiveness of formal or informal appropriability. Furthermore, the effectiveness of a firm's appropriability mechanisms is contingent on the nature of the firm, specifically the openness of its innovation strategy and whether it is knowledge-intensive. These two important boundary conditions shape the interplay among appropriation, type of firm, and innovation performance (specifically, turnover from new products).

Compared with manufacturers, innovation in service firms is less centralised and less formally organised, and intangible assets such as human-based and organisational features are more important (Blindenbach-Driessen and Van den Ende, 2014; Leiponen and Byma, 2009; Tether, 2005). These characteristics of service firms limit the effectiveness of appropriability mechanisms suitable for manufacturing firms (and vice versa).

Relatively speaking, the products of manufacturing firms are built strongly on codified, explicit knowledge, whereas the products of service firms tend to rely more on tacit knowledge in the form of service personnel experience (Hitt et al., 2001). Similarly, the literature distinguishes between two types of appropriability. Patents, trademarks, industrial designs, and copyrights

are formal institutionally based mechanisms relying on codified knowledge. Informal mechanisms (e.g., secrecy, lead time, design complexity) are less suited to explicit knowledge, relying instead on keeping knowledge tacit to make it more difficult to share or leak (Hall et al., 2014; Henttonen et al., 2016). This suggests an alignment between appropriability mechanisms and the manufacturing–services divide. However, the relative effectiveness of formal and informal appropriability for services and manufacturing has not been fully explored, and the conditions under which they have more influence on innovation performance are unclear.

While deciding on how to appropriate returns from innovation, firms also pursue more open innovation strategies, such as collaborating with a broader range of external partners, resulting in greater amounts of knowledge crossing organizational boundaries (Chesbrough et al., 2006). In turn, this creates a dilemma for firms, termed the "paradox of openness" (Laursen and Salter, 2014). Lauritzen and Karafyllia (2019) suggest that firms can manage the paradox of openness by treating appropriation and openness as either conflicting elements or complementary and mutually enabling elements. Maximising the appropriation of returns from innovation often necessitates deploying protection mechanisms, which can curtail the ability to effectively collaborate (Dahlander and Gann, 2010). In addition, informal mechanisms such as secrecy may become less effective in protecting knowledge when firms pursue collaborative strategies because the risk of knowledge leakage increases (Liebeskind, 1997). However, research argues that formal appropriability mechanisms signal that firms hold important information and, consequently, can attract more external partners (Alexy et al., 2009). Emergent research suggests that, when navigating the paradox of openness, more formal mechanisms may exacerbate the problem, while informal ones may limit the problem (Foege et al., 2019).

This situation suggests a lack of clarity as to whether synergies between openness and appropriation bear out in practice or negative outcomes emerge, as well as uncertainty as to whether the paradox of openness applies to both formal and informal mechanisms. Thus, studies have called for further research on the interaction between openness and appropriability mechanisms for innovation performance (Stefan and Bengtsson, 2017; Veer et al., 2016; Zobel et al., 2016). Furthermore, understanding on how service firms enact the paradox of openness is lacking (Miozzo et al., 2016). Compared with manufacturers, innovating service firms collaborate and exchange knowledge more with customers and suppliers (Mina et al., 2014; Tether, 2005). This suggests that the choice and effectiveness of appropriability mechanisms, and thus the paradox of openness, differ in service firms.

Evidence suggests that the heterogeneity between services and manufacturing is not as great as the differences between sectors within each (Forsman, 2011; Storey et al., 2016). Knowledge-intensive firms are those that are relatively intensive in their inputs of technology and human capital (OECD, 1999). They deliver customized offerings based on idiosyncratic tacit knowledge delivered by complex ecosystems that are markedly different from other firms (Arbussa and Coenders, 2007; Mina et al., 2014; Miozzo et al., 2016). Common wisdom is that knowledge-intensive firms (manufacturing and services) innovate more and therefore are more in need of appropriation (Arbussa and Coenders, 2007). However, at the same time, the complexity and tacitness of knowledge help protect knowledge-intensive firms' innovations from imitation (McEvily and Chakravarthy, 2002).

We propose that the impact of formal and informal appropriation mechanisms on innovation performance will be contingent on the extent to which firms are knowledge-intensive, limiting or exacerbating the differences between manufacturing and service firms. This suggests a continuum from discrete product manufacturing firms, whose products rely heavily on

codified, explicit knowledge, to knowledge-intensive service firms, which tend to rely more on complex tacit knowledge. The relative impact of informal (vs. formal) appropriation on innovation performance will increase along this continuum.

To address the gaps in the appropriability and open innovation literature streams, this empirical study, using a dataset from the U.K. Community Innovation Survey (CIS), investigates how manufacturing and service firms use formal and informal mechanisms to appropriate the returns from innovation and examines the impact of the boundary conditions of the breadth of external collaboration and whether firms are knowledge-intensive. Thus, this study constructs a more integrative and holistic understanding of the contingencies of appropriation for manufacturing and service firms.

2. Conceptual background

2.1. Appropriability mechanisms for innovation performance

Table 1 presents a summary of key studies that specifically explore the impact of appropriability mechanisms on firms' innovation activity or innovation performance[1]. Research has shown that the use of all appropriability tools, both formal and informal, is associated with undertaking innovation (Arbussa and Coenders, 2007; Hanel, 2008; Thomä and Bizer, 2013). However, relatively few studies have explored the link between appropriability and the contribution of innovation to sales or profit.

INSERT TABLE 1

[1] Studies are limited to those published in the Charted Association of Business School Academic Journal Guide (https://charteredabs.org/academic-journal-guide-2018). Only articles showing relationships between innovation performance (or activity) and formal or informal appropriability mechanisms are included.

Although the use of appropriability mechanisms is positively associated with innovation performance (Lee et al., 2018), this holds only for incremental innovation (Hurmelinna-Laukkanen et al., 2008). Furthermore, whether both formal and informal mechanisms are important for innovation performance is unclear. Laursen and Salter (2005) showed that both, to a limited extent, are associated with innovation performance. However, Chang and Chen (2016) suggest that it is the use of informal tools, rather than formal tools, that determines whether firms are product innovators, whereas Olander et al. (2014) found that formal appropriability mechanisms aid value capture (commercializing innovation), with informal tools having no impact. These contrasting findings of the effectiveness of formal and informal appropriability suggest that contingent factors, such as the type of firm, are at play.

For manufacturing firms, research has found that formal appropriability mechanisms are positively associated with innovation performance (Hall et al., 2013; Hussinger, 2006; Laursen and Salter, 2005). Results are mixed, however, regarding informal mechanisms. Hanel (2008) found a relationship between trade secrets and undertaking incremental innovation, whereas Hussinger (2006) found no relationship between secrecy and innovation performance. Service companies employ less formal types of appropriation than goods firms (Gallié and Legros, 2012; Leiponen and Byma, 2009), relying on informal mechanisms (Miles et al., 2000). For services, research has found a positive association between informal (vs. formal) mechanisms and innovation performance (Chang and Chen, 2016; Elche-Hotelano, 2011).

Research has explored the use of appropriability mechanisms in knowledge-intensive firms (manufacturing and services), as these firms innovate more and use appropriation to a greater extent (Arbussa and Coenders, 2007; Thomä and Bizer, 2013). However, the implications are far from clear-cut. Formal and informal tools are often complements for knowledge-intensive firms but substitutes for other firms (Lee et al., 2018). Gallié and Legros (2012) found that

technology-driven firms use more informal types of appropriability. For knowledge-intensive services, the use of informal tools drives innovation (Thomä and Bizer, 2013), while formal appropriability is negatively associated with producing new-to-firm innovation performance (Hall et al., 2013).

2.2. Openness and appropriability

Innovation strategies are now more open (Chesbrough et al., 2006), and the extent to which firms search for external knowledge or collaborate with external partners can significantly affect innovation performance (Laursen and Salter, 2006; Love et al., 2014). Maximising innovation performance necessitates deploying appropriation strategies, but the strong use of appropriation can have adverse effects on external searching and collaboration (Laursen and Salter, 2014; Miozzo et al., 2016). Wang et al. (2017) found a negative association between patenting and the inflow of knowledge to the firm; this is the paradox of openness (Laursen and Salter, 2014): innovation strategies typically involve collaboration with external partners necessitating being open with knowledge whilst appropriating returns from innovation requires formal or informal knowledge protection mechanisms.

Much of the past research has examined formal appropriability mechanisms. For example, Arora et al. (2016) found that high-performing innovation leaders are more likely to employ patents, but this is contingent on their collaborating with external partners; Veer et al. (2016) found that formal appropriability mechanisms stop imitation resulting from R&D partnerships. However, Xu et al. (2012) showed that external knowledge sourcing reduces the impact of informal appropriability tools on a firm's innovation activity but increases the impact of formal tools.

Recent research suggests that the paradox of openness is not universal and has begun exploring contingencies such as a firm's innovation strategy (Arora et al., 2016), the degree of knowledge

distance between collaborators (Pollok et al., 2019), and the type of knowledge shared (Foege et al., 2019). However, relatively scant research has explored the interplay between appropriability and collaboration breadth for innovation performance, specifically for service firms. Collaboration involves a two-way flow of knowledge, which makes the paradox of innovation more prevalent. For example, the negative side of appropriability is greater in the context of collaboration than simply inbound knowledge flows (Foege et al., 2019; Laursen and Salter, 2014), and this is a particular issue for service firms, given their prevalence for collaboration in innovation (Tether, 2005).

3. Hypotheses

We propose that the relative effectiveness of formal versus informal appropriability mechanisms for innovation performance (turnover from products new to the market) will be different for service and manufacturing firms. Namely, formal mechanisms will be more effective for manufacturing and informal for services. However, two boundary conditions will moderate this effectiveness: the openness of a firm's innovation strategies (specifically the number of collaboration partners) and whether the firm is knowledge-intensive. Both conditions are quasi moderators as both collaboration and knowledge intensity are related to innovation performance (Prescott, 1986). Figure 1 depicts our conceptual model.

INSERT FIGURE 1

3.1. Formal versus informal appropriability for innovation performance

In general, appropriability mechanisms are beneficial for innovation performance. Previous studies have highlighted the underlying differences between formal and informal appropriability mechanisms (Gallié and Legros, 2012; Hurmelinna-Laukkanen and Puumalainen, 2007; Zobel et al., 2017). We propose that the effectiveness of formal versus

informal appropriability mechanisms will be contingent on the nature of the knowledge that is being protected. Formal protection mechanisms are codified, institutionally based mechanisms, whereas informal mechanisms are more suited to protecting tacit knowledge (Amara et al., 2008; Hall et al., 2014; Henttonen et al., 2016). This suggests that the usefulness of formal versus informal mechanisms will be different between manufacturing and service firms.

Relatively speaking, the products of manufacturing firms are built strongly on codified, explicit knowledge (Hitt et al., 2001), and managers of product innovation in sectors that generate discrete products rate patents as more effective (Cohen et al., 2000). For manufacturing firms, innovation performance is related to formal appropriation, but the impact of informal mechanisms is limited (Hanel, 2008; Hussinger, 2006; Zobel et al., 2017). This suggests that for manufacturing firms, formal appropriability mechanisms are relatively more important than informal mechanisms.

The products of service firms tend to rely more on tacit knowledge in the form of the expertise of service personnel (Hitt et al., 2001; Storey and Khan, 2010). In addition, innovation in services is less formally organised, distributed throughout the organization, and less technologically based (Blindenbach-Driessen and Van den Ende, 2014; Tether, 2005). As a result, service firms rely on informal appropriability mechanisms (Miles et al., 2000), though formal mechanisms can be employed alongside (Chang and Chen, 2016). The tacitness of knowledge inherent in service firms enables more effective knowledge protection through the use of lead time and secrecy than through patents. Whereas Hall et al. (2013) showed that formal appropriability mechanisms are associated with innovation performance, other research has found a positive impact of informal (vs. formal) appropriation (Elche-Hotelano, 2011). Research in the service sector has also shown that informal appropriability is more frequent in in firms without formal R&D units (Miles, 2007). Therefore, we expect that the impact of

informal appropriability mechanisms will be greater for service than manufacturing firms and hypothesise the following:

H1a: *Formal appropriability has a stronger influence on innovation performance in manufacturing firms than informal appropriability.*

H1b: *Informal appropriability has a stronger influence on innovation performance in service firms than formal appropriability.*

3.2. The moderating effect of collaboration breadth

Innovation collaboration involves a two-way flow of knowledge, which increases the need for appropriation mechanisms (Alexy et al., 2009; Chesbrough et al., 2006). However, excessive protectionism can have adverse effects on relationships with collaboration partners (Huang et al., 2014; Laursen and Salter, 2014). The use of appropriability mechanisms signals mistrust in partners and discourages the sharing of knowledge (Miozzo et al., 2016; Wang et al., 2017). We suggest that this paradox of openness will be contingent on the interplay between the nature of the appropriability mechanism (formal vs. informal) and the tacitness of the knowledge being protected. As such, it will have differing effects for service and manufacturing firms.

Formal mechanisms such as patents, copyrights, and trademarks represent the codification of knowledge, enabling the safe transfer of knowledge that would, without these protection mechanisms, be easy to imitate (Alexy et al., 2009; Pisano, 2006). Formal appropriability mechanisms signal the generation and retention of significant knowledge, and therefore firms can attract more external partners (Alexy et al., 2009; Henttonen et al., 2016). Furthermore, they enable firms to reveal sufficient technical details about problems and opportunities to attract potential collaborators (Pollok et al., 2019). Formal mechanisms also signal that both partners are willing to engage in mutual knowledge exchange without expropriation or imitation, which facilitates the sharing of knowledge more openly (Foege et al 2019; Veer et

al., 2016). These mechanisms can also encourage partners to invest more in the relationship to improve returns. Thus, the signalling effects of formal mechanisms tend to counterbalance their constrictive effects, reducing the effect of the paradox of openness. Lauritzen and Karafyllia (2019) suggest that firms can treat appropriation and openness as complementary and mutually enabling elements.

However, these counterbalancing forces do not apply to informal mechanisms. Mechanisms such as secrecy may become less effective when pursuing collaborative strategies. The risk of knowledge leakage in using secrecy is higher when companies are collaborative (Liebeskind, 1997). Informal mechanisms have the direct, specific, and intended effect of restricting knowledge flow between firms (Huang et al., 2014), limiting the effectiveness of collaboration. This suggests that the use of informal appropriability mechanisms hinders firms from further collaboration with external parties because of the danger of the loss of control over knowledge and, as a result, diminishes the positive effects of external collaboration on innovation performance. Thus:

> H2a: *The extent to which collaboration breadth mitigates the effectiveness of appropriability on innovation performance is greater for informal than formal mechanisms.*

The above discussion suggests that the impact of collaboration breadth will be different for manufacturing and service firms. Service firms employ more knowledge sources and engage in more collaboration with their customers and suppliers than manufacturing firms do (Tether, 2005). This implies that the paradox of openness may be stronger for service firms.

Service innovation relies more on employees' knowledge, and a greater emphasis on secrecy causes discontent and a lack of trust among employees. This can inhibit learning, increase monitoring costs, and decrease the effectiveness of collaboration (Liebeskind, 1997, Miozzo

et al., 2016). In service firms, innovation is distributed throughout the organization (Blindenbach-Driessen and Van den Ende 2014), which makes knowledge leakage more likely when collaborating with a broader range of external organisations. The reliance of service firms on co-production with customers exposes some of their knowledge and competencies to the customers (De Vries, 2006), who are then likely to transfer the knowledge to other firms (Hitt et al., 2006). Given the continuous interaction with customers, the effectiveness of tacitness and secrecy as protection mechanisms erodes (Hannah, 2005). Thus:

H2b: *The extent to which collaboration breadth mitigates the effectiveness of appropriability on innovation performance is greater for service firms than manufacturing firms.*

3.3. The moderating effect of knowledge intensity

We propose that the extent to which firms are knowledge-intensive will moderate the relative usefulness of formal and informal appropriability mechanisms. Knowledge-intensive firms tend to rely on complex tacit knowledge to effectively deliver value. Products in these firms are servitised, offering integrated product and service solutions, which often requires complex ecosystems to deliver value (Mina et al., 2014). Knowledge-intensive firms also offer a high degree of customisation, requiring the exchange of tacit knowledge in an iterative co-creation process (Miozzo et al., 2016). The exchange of knowledge implies that knowledge-intensive firms may be in more need of appropriation, but at the same time the tacitness of knowledge may help protect knowledge-intensive firms.

Knowledge-intensive manufacturing firms with technologically complex products require a different approach to innovation than firms developing products using less complex codified knowledge (Arbussa and Coenders, 2007; Lee et al., 2018; Leiponen and Byma, 2009). McEvily and Chakravarthy (2002) found that the complexity of technological knowledge

protects manufacturing firms' innovations, slowing imitation. For manufacturing firms, research has shown that patents are the most important tool for capturing the returns from innovation in which knowledge is codified in discrete products (Cohen et al., 2000).

Similarly, significant differences in innovation practices exist between service firms that are reliant on the tacit knowledge held by their employees and firms that use explicit processes (Storey et al., 2016; Storey and Kahn, 2010). Converting tacit organizational knowledge into a codified form that can be used by formal appropriability mechanisms is difficult (Hurmelinna-Laukkanen et al., 2007). Amara et al. (2008) argued that, given the intangible nature of their services, knowledge-intensive service firms are more suited to informal protection mechanisms and that formal appropriation may even harm innovation performance. Formal mechanisms are better suited to services characterized by a high degree of knowledge codification and tangible outputs (Hall et al., 2013). Formal processes and structures that ensure the capture, analysis, interpretation, and integration of knowledge during development are thus more powerful when the knowledge to be shared is explicit rather than tacit (Storey and Kahn, 2010). As such, we argue that the effectiveness of informal appropriability (vs. formal appropriability) will be greater for knowledge-intensive firms:

H3: *The relative impact of informal (vs. formal) appropriability on innovation performance is greater for high knowledge-intensive firms*.

Specifically, for manufacturing and service firms, we hypothesise the following:

H4a: *In low-knowledge-intensive manufacturing firms, formal appropriability has a stronger influence on innovation performance than informal appropriability.*

H4b: *In high-knowledge-intensive service firms, informal appropriability has a stronger influence on innovation performance than formal appropriability.*

4. Data and method

4.1. Data

The dataset comes from the U.K. CIS data that covers the years between 2008 and 2010 (Department of Enterprise, Trade and Investment, 2018). The questions used in the surveys are described in the OECD (2005) *Oslo Manual*. Previous studies have used this dataset and confirmed its validity and reliability (e.g., Laursen & Salter, 2014; Veer et al., 2016).

The 7th U.K. CIS was administered in 2011 by the U.K. Office for National Statistics (ONS). The survey was sent to firms with more than 10 employees and has a 51% response. In this study, we used data from firms with non-missing values and that had declared innovation activities. This equated to 1,618 manufacturing and 5,560 service firms. We ran Harman's one-factor test on the designated items in our study. The results show that the primary factor was less than 50% of the variance (30% for manufacturing, and 26% for services) and therefore does not indicate potential issues related to common method bias (Podsakoff and Organ, 1986).

4.2. Measures

We use radical innovation performance to reflect firms' *innovation performance*. Radical innovation is measured by the percentage of companies' total turnover in relation to goods or services that are new to the market. We then computed logarithmic transformations for the variable to enhance the normality of the distributions. Previous innovation research has also applied this measure (e.g., Laursen and Salter, 2006).

To measure *appropriability mechanisms*, we categorise seven sources of appropriability as *formal* (patents, industrial design, trademarks, and copyrights) and *informal* (secrecy, complex design, and lead time) (e.g., Zobel et al., 2017). The U.K. CIS asks whether the firm uses/registers (1) each of the seven mechanisms or not (0). The scores for formal and informal mechanisms were summed.

For *collaboration breadth*, we used an established measure (Laursen and Salter, 2014; Love et al., 2014). Firms were asked to report whether they had collaborated (or not) on innovation activities with any of the following six external partners: (i) suppliers, (ii) customers, (iii) competitors, (iv) consultants, (v) universities, and (vi) government or public research institutes. We sum these to give a measure of collaboration breadth from 0 (no collaboration) to 6 (collaborates with all external actors).

To account for the nature of knowledge, we categorise manufacturing and service firms as *low-* and *high-knowledge-intensive* firms according to the NACE codes from the Eurostat classification in the CIS. Both high-tech firms in the manufacturing sector (e.g., electronic, aerospace, petro-chemicals) and knowledge-intensive service sectors (e.g., professional, education, information, and communications) are included in OECD's (1999) definition of knowledge-intensive industries as firms that are relatively intensive in their inputs of technology and human capital. Prior studies have also employed this classification (Amara et al., 2008; Arbussa and Coenders, 2007). In the analysis, we exclude medium-knowledge-intensive firms to better account for the impact of high- versus low-knowledge-intensive firms as also evidenced by previous studies (e.g. Miozzo et al, 2016).

4.3. Control variables

To increase the validity and robustness of the quantitative study, we add several control variables as determinants of innovation performance that previous innovation studies have used and validated. *R&D intensity* measures firm R&D expenditure divided by turnover to control for absorptive capacity (Cohen and Levinthal, 1990). We also control for the *number of employees* (transformed into a logarithmic expression). The data for turnover and employees came from ONS register data.

In addition, we account for the *start-up* factor by incorporating a measure on whether the company was founded after 2008. *Market size* controls for companies' involvement in various markets such as the U.K. local, U.K. national, or international markets. We include 12 *geographic dummies* to control for potential regional differences.

To alleviate any concerns that a self-selection bias exists in the interplay between external collaboration and appropriability mechanisms by "high-quality" firms, we add two high-quality proxies (Laursen and Salter, 2014). These are *human capital*, which we calculate as a percentage of employees who hold a bachelor's degree or in the company, and *labour productivity*, which is the ratio of revenue to the number of employees[2].

5. Results

Table 2 and Table 3 list the descriptive statistics and correlations for manufacturing and services. None of the correlations are above 0.5, and no variance inflation factors are greater than 3, suggesting that multi-collinearity is not an issue. Manufacturing firms appear, on average, to have a wider collaboration breadth (1.19) than service firms (0.70)[3], though the standard deviation is higher in manufacturing. In addition, manufacturing firms deploy approximately two times more formal (0.41) and informal (0.45) mechanisms than service firms, with formal (0.18) and informal (0.18) mechanisms, respectively.

INSERT TABLES 2 AND 3

Table 4 and Table 5 display descriptive statistics by industry. Knowledge-intensive manufacturing firms (e.g., chemicals, electronics) and knowledge-intensive service firms (e.g.,

[2] As a robustness check, we ran the analysis without these two variables. The regression results are unchanged from the original case and are still highly significant with similar magnitudes. This confirms the validity and strength of the relationship among external collaboration, appropriability, and innovation performance.

[3] The data do not show the number of partners in each category, and service firms may collaborate with more customers than manufacturers do (Tether, 2005).

information and communications, professional and scientific activities) engage in greater external collaboration, use more appropriability mechanisms, and have a higher proportion of sales from radical innovation.

INSERT TABLES 4 AND 5

We measure our dependent variable for innovation performance as a percentage of total turnover, which, by definition, has values between 0 and 100. As such, tobit regression analyses are most suitable (Wooldridge, 2010) for testing the hypotheses. However, the data should have a normal distribution under the tobit model. This is not the case for innovation performance, which is skewed and concentrated towards zero. A way to solve this problem is to apply a logarithmic transformation ($Y^* = \ln(1 + Y)$) to the dependent variable (Wooldridge, 2010); we do so in the subsequent analysis (Laursen and Salter, 2006).

Model 1 in Table 6 shows the result of the tobit regressions on the impact of appropriability mechanisms on innovation performance, and Model 2 shows the effect of firm type. Manufacturing has a positive interaction with formal tools (0.184, $p \leq 0.1$) but a negative interaction with informal appropriability (–0.398, $p < 0.001$). By contrast, in service firms, the relative impact of informal appropriability increases, while that of formal appropriability decreases. Further investigation of the simple slopes for manufacturing and service firms shows that formal and informal appropriability mechanisms have a significant impact on innovation performance in both cases. We used slope significance tests (Cohen et al., 2013) to assess whether the differences between formal and informal mechanisms were significant. For manufacturing firms, although formal appropriability mechanisms has a stronger influence on innovation performance than informal, the difference is not significant ($t = 0.74$, *n.s.*), failing to support H1a. For service firms, informal appropriability has a significantly greater impact than formal mechanisms ($t = 4.91$, $p < 0.001$), validating H1b.

INSERT TABLE 6

Model 3 in Table 6 presents the results for the moderating effect of collaboration breadth on the relationship between appropriability mechanisms and innovation performance. Collaboration mitigates the effectiveness of formal appropriability (–0.109, $p < 0.001$) and informal appropriability (–0.137, $p < 0.001$) on innovation performance, demonstrating the paradox of openness. While collaboration requires appropriation, the usefulness of appropriation for innovation performance is curtailed. However, we do not find support for H2a. The moderating effect of collaboration is greater for informal appropriability, but the difference is not significant.

However, the three-way interaction (Model 4 in Table 6) shows that there are differences depending on firm type (manufacturing versus services) for formal (-0.139; $p < 0.05$) but not informal appropriability (0.015; *n.s.*). To help understand the effects, we graph these results in Figure 2, showing the moderating effects of collaboration separately for manufacturing and service firms.

The results for H2b are surprising. The paradox of openness appears to be stronger for manufacturing firms. Examining the simple slopes shows that under conditions of high collaboration neither formal (0.54; *n.s.*) nor informal (0.35; *n.s.*) appropriability has a significant impact on innovation performance. The effect for formal appropriability is quite striking. At high levels of formal appropriability, we found no difference in innovation performance between firms that collaborate and those that do not. The same does not hold for service firms. While collaboration significantly reduces the usefulness of informal appropriability, this is still outweighed by the benefits from collaboration. The impact is still significant (0.73; $p < 0.01$). Formal appropriability is non-significant under high collaboration (0.29; *n.s.*).

INSERT FIGURE 2

Table 7 shows the regressions results for the impact of knowledge intensity on the relationship between appropriability mechanisms and innovation performance. For knowledge-intensive firms (Model 1), informal appropriability has a greater positive association (0.276, $p < 0.05$) with innovation performance, while formal appropriability has a significantly lower impact (–0.388, $p < 0.01$). Further exploration reveals that for knowledge-intensive firms, formal appropriability has no impact on innovation performance (0.03, *n.s.*). Thus, we confirm that the relative impact of informal (vs. formal) appropriability on innovation performance is increased for knowledge-intensive firms, in support of H3.

INSERT TABLE 7

Model 2 in Table 7 shows the results of the three-way interactions, which we graph in Figure 3. Our results show that the impact of knowledge-intensity on the appropriability-performance link is consistent between manufacturing and service firms. Simple slopes of the appropriability–innovation performance relationship across the four configurations of firms (for both formal and informal appropriability) reveal important differences. For low-knowledge-intensive manufacturing firms, only formal appropriation (0.53, $p < 0.01$), not informal (0.22, *n.s.*), has a significant impact on innovation performance, in support of H4a. For high-knowledge-intensive service firms, we find the opposite. Informal appropriability is significant (0.65, $p < 0.01$), but formal mechanisms are not (0.05, *n.s.*), in support of H4b. In between are low-knowledge-intensive services in which both informal (0.42, $p < 0.01$) and formal (0.40, $p < 0.01$) appropriability are significant. Knowledge-intensive manufacturing firms are closer to knowledge-intensive service firms than other less knowledge-intensive firms. For knowledge-intensive manufacturing firms, informal appropriability is significant (0.56, $p < 0.01$), but formal appropriability is not (0.10, *n.s.*).

INSERT FIGURE 3

Table 8 summarises our results showing whether each hypothesis was confirmed or not.

INSERT TABLE 8

5.1. Post hoc analysis

Though not hypothesised, we examined the interaction effect of collaboration breadth, knowledge intensity, and firm type on the appropriability–innovation performance relationship. We performed a sub-group analysis for the four manufacturing/service and high-/low-knowledge-intensive firm types (see Table 9). Sub-group analysis is useful for categorical variables and for examining the strength of relationships (Prescott, 1986). For service firms, collaboration only moderates informal appropriability, but this is consistent across high- (–0.10, $p < 0.05$) and low-knowledge-intensive firms (–0.12, $p < 0.05$). In high-knowledge-intensive manufacturing firms, collaboration breadth only mitigates the effect of formal appropriability (–0.20, $p < 0.01$). Notably, we find the opposite for low-knowledge-intensive manufacturing firms. Collaboration mitigates the effect of informal protection (–0.37, $p < 0.05$) on innovation performance rather than formal mechanisms.

INSERT TABLE 9

5.2. Robustness checks

We performed additional analyses to check for the robustness of our results and exclude alternative explanations. We ran quadratic regression analyses with squared terms for collaboration breadth (e.g., Laursen and Salter 2006, 2014) throughout all models for both manufacturing and service firms. Including the quadratic term does not affect the results. While collaboration breadth squared has an inverted U-shaped relationship to innovation performance (–0.238, $p < 0.001$), we found no evidence of a significant interaction between the quadratic

term and either formal (= 0.034, *n.s.*) or informal (= –0.502, *n.s.*) appropriability. The coefficients and significance levels of the rest of the models are consistent. We also ran the same analyses with a fractional logit regression (Papke and Wooldridge, 1996): the results, significance, and variable magnitudes are consistent with the tobit regressions.

It may be that different types of partners affect the usefulness of appropriability mechanisms differently. Therefore, we ran all our hypotheses with each distinct external partner type (suppliers, customers, competitors, consultants, universities, and government or public research institutes). The overall results are consistent with our aggregate variable of collaboration across different types of partners, despite previous research warning of the danger of knowledge leakage and imitation when collaborating specifically with customers (De Vries, 2006; Veer et al., 2016). The detrimental aspects of customer collaboration seem no worse than with other partners.

6. Discussion

6.1. Theoretical contributions

This paper contributes to the extant academic discussion on the paradox of limits of appropriation and how two boundary conditions (the openness of a firm's innovation strategy and whether the firm is knowledge-intensive) affect the relative impact of formal and informal appropriability on innovation performance in manufacturing and service firms. This study examines the challenges that companies must address when formulating and deploying appropriability mechanisms and, in doing so, makes several important contributions to the literature.

First, we contribute to appropriability theory, providing empirical evidence for the relative importance of formal versus informal appropriability, and outline the contingencies under which each should be accentuated for innovation performance. The results show that

manufacturing firms benefit from both formal and informal mechanisms (Laursen and Salter, 2005). This contradicts previous research that shows that informal appropriability is not associated with innovation performance (Hussinger, 2006; Zobel et al., 2017). Service firms also benefit from both mechanisms, though they gain significantly better innovation returns from informal appropriability. Previous research has found that only informal mechanisms are associated with innovation performance (Elche-Hotelano, 2011). This suggests that other factors are at play that may affect the relative effectiveness of formal and informal appropriability beyond the services–manufacturing dichotomy.

Second, we contribute to the literature on open innovation, adding to the emergent academic debate on the paradox of openness (Arora et al., 2016; Laursen and Salter, 2014; Pollok et al., 2019) and, more specifically, on the contingent factors in the openness–appropriability discussion (Foege et al., 2019; Veer et al., 2016). This is important because research has shown a positive relationship between external collaboration and appropriability mechanisms (Mina et al., 2014; Miozzo et al., 2016). This study adds a new layer to the debate by showing that the impact of the nature of the knowledge between and within manufacturing and service firms helps explain some of the contradictory findings of the effectiveness of formal and informal mechanisms in previous research.

We found that for service firms, the paradox of openness is not as serious a problem as expected. Rather, we provide evidence that service firms can manage the paradox of openness by treating appropriation and openness as complementary and mutually enabling elements (Lauritzen and Karafyllia, 2019). Under conditions of high collaboration, service firms still benefit from employing appropriability mechanisms. While the necessary knowledge sharing inherent in collaboration mitigates the effectiveness of informal mechanisms, the benefits from collaboration outweigh any adverse effects on appropriability mechanisms. The tacit nature of

knowledge in service firms makes it difficult for competitors to take advantage of knowledge leakages (McEvily and Chakravarthy, 2002). By contrast, the openness paradox appears to be stronger for manufacturers. External collaboration mitigates the effectiveness of both formal and informal mechanisms, particularly formal appropriation. At high levels of formal appropriation, the benefits of collaboration disappear, suggesting that these are conflicting, rather than complementary, elements for manufacturing (Lauritzen and Karafyllia, 2019).

Finally, this study extends understanding of how service firms differ from manufacturing firms when engaging in innovation activities (Ettlie and Rosenthal, 2011; Miozzo et al., 2016). In particular, the results suggest that knowledge intensity is more important than the manufacturing–services dichotomy in understanding differences between firms. Storey et al. (2016) suggest that explicit service innovation sits interstitial between tacit service and product innovation. Mina et al. (2014) found that the differences in innovation activities between service firms and manufacturers disappears for high-tech manufacturing. We suggest that there is a continuum from low-knowledge-intensive manufacturers to high-knowledge-intensive service firms. The relative effectiveness of formal versus informal mechanisms along this continuum is contingent on the nature of the knowledge that is being protected and the extent to which that tacit knowledge is embedded in the product on offer. Knowledge-intensive firms do not benefit from formal appropriation; rather, the impact of informal appropriation increases for these firms.

For knowledge-intensive service firms with complex tacit knowledge embedded in their products, only informal appropriability has an impact on innovation performance. Formal appropriability has no impact, though there is no evidence of the negative effects found previously (Hall et al., 2013). At the other extreme, for low-knowledge-intensive manufacturers, in which knowledge is codified in discrete products (Cohen et al., 2000), only formal methods are associated with innovation performance. In between are firms that offer

standardized process-oriented services built on explicit knowledge (Storey and Kahn, 2010). For these firms, both formal and informal appropriability mechanisms are useful. Knowledge-intensive manufacturers that produce servitised offerings requiring complex ecosystems, rather than simple discrete products, sit closer to knowledge-intensive services than other manufacturers. As such, they benefit only from informal appropriability. This suggests that, in terms of the effectiveness of appropriability mechanisms, the heterogeneity within service firms and within manufacturing firms is greater than the heterogeneity between services and manufacturers.

The degree of knowledge intensity also clouds the issue regarding the paradox of openness. This is important because open innovation practices are also associated with the adoption of servitisation in manufacturing firms (Mina et al., 2014). We found that for knowledge-intensive servitised manufacturers, only informal appropriability mechanisms are linked to innovation performance. However, under conditions of low collaboration, formal mechanisms also have an impact, suggesting that for these firms, the paradox only applies to formal mechanisms.

For low-knowledge-intensive manufacturers, the degree of collaboration does not affect the importance of formal appropriability, suggesting that the paradox is not an issue. Also as expected, under high collaboration, informal appropriability does not have an impact on innovation performance. However, under low collaboration, informal mechanisms are positively associated with innovation performance. For these discrete product manufacturers, high informal appropriation without collaboration may be the best strategy. Using secrecy effectively is easier when there are limited points of connection to other organizations. Non-disclosure agreements are easier to monitor and enforce. A further explanation may be that these firms rely on short lead times as a means of driving innovation success. Collaboration

with multiple partners can add complexity to the development process, increasing development times. However, further research is necessary to confirm this explanation.

6.2. Managerial implications

Managers should be aware that there is no one-size-fits-all approach to appropriability, openness, and innovation performance. Both formal and informal appropriability are associated with higher degrees of innovation performance. However, it would be incorrect to suggest that all firms should invest equally in both. Appropriation costs money, and implementing the incorrect strategy will have an impact on the returns from appropriation. The results also imply that collaboration may not be beneficial for all. We draw guidelines from these results that may help managers along the knowledge continuum maximise their innovation performance:

- *Knowledge-intensive services:* These firms should invest in informal appropriation but should think carefully about investing in formal appropriation. Open innovation will bring additional rewards and should be pursued.
- *Knowledge-intensive, servitised manufacturers:* These firms should also invest in informal mechanisms and engage in open innovation. However, if they do not collaborate, formal appropriability may also be deployed.
- *Standardized process-oriented service firms:* These firms benefit from investing in both formal and informal appropriability mechanisms. They should do so regardless of the degree of collaboration.
- *Discrete product manufacturers:* These firms should invest only in formal appropriation if they are collaborating. However, if development speed is important, they should limit collaboration, as this may curtail performance. If development speed is less crucial, collaboration will be beneficial.

6.3. Limitations and future research

Future research could address some of the limitations of this research. First, the U.K. CIS involves cross-sectional data, and as such, drawing causality among appropriability, collaboration breadth, and innovation performance is difficult. Future studies might complement the dataset (ideally panel data) with additional information on companies' IP stocks, such as patents, trademarks, registration of industrial design, and copyrights. The data do not directly explore the motivations for employing appropriation mechanisms, which may not be protection (Block et al., 2015). Further research could examine whether motivations of the use of appropriation affect the results.

This paper explores differences between service and manufacturing firms in high- and low-knowledge-intensive sectors. It follows previous research in taking a standard industry classification approach. However, considerable variation may exist in the way firms compete that may transcend standard sector classification. A more nuanced understanding could be attained by examining the explicit knowledge strategies of individual firms. In addition, post hoc analysis showed that the results were consistent across different types of collaboration partners. Control of knowledge leakage to customers may be a problem when collaborating with multiple customers; however, currently the data do not allow testing of this.

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Table 1. Overview of key empirical studies on appropriation mechanism and innovation

Study	Key findings related to appropriation mechanisms and innovation	Sample characteristics
Arbussa and Coenders (2007)	Use of appropriation tools is associated with carrying out R&D and downstream product innovation activities. Manufacturing and high-knowledge firms are more active in R&D (effects on appropriation not explored).	Spanish CIS data; manufacturing and services; low- and high-tech/knowledge firms.
Arora et al. (2016)	Innovation leaders (% of profit from new products; R&D expenditure) are more likely to employ patents but contingent on them being open. Open firms use more patents.	U.K. CIS & additional data
Chang and Chen (2016)	Product innovators make more use of either informal appropriation tools or both formal and informal tools together. No clear patterns by service sectors.	Taiwanese service firms
Elche-Hotelano (2011)	There is a positive association between informal (but not formal) appropriation and innovation performance (% of sales from new or improved products).	Spanish service firms.
Gallié and Legros (2012)	Firms engaged in product innovation activity are associated with use of all types, except secrecy and copyrights. Service (goods) firms use less (more) formal types of appropriation. Technology-driven firms use more informal types.	French CIS data; goods and services firms.
Hall et al. (2013)	Use of formal (patents and trademarks) appropriation mechanisms have positive impact on sales from new-to-market products (but not new-to-firm products). For KIBS, use of patents is negatively associated with sales from new-to-firm innovations. Innovators rate informal means of protection as more important than formal means.	U.K. CIS & additional data; manufacturing and services (KIBS vs. others).
Hanel (2008)	All appropriation tools are associated with undertaking innovation. Patents are most important for producing new-to-market innovations; secrecy for new-to-firm innovations.	Canadian innovation survey; manufacturing firms
Hurmelinna-Laukkanen et al. (2008)	Perceived strength of appropriability mechanisms is positively associated with innovation performance (% sales from new products) when innovation is incremental (modification of existing products). No relationship found with radical innovation performance (new-to-market or new-to-firm).	Finnish manufacturing firms
Hussinger (2006)	The use of patents is positively associated with the success of firms' innovation in the market (% sales from new products). No relationship for use of secrecy.	German CIS data; manufacturing firms.
Laursen and Salter (2005)	Formal and informal appropriability mechanisms are associated with innovation performance (% profits from new products) with decreasing returns. Formal and informal mechanisms are substitutes.	U.K. CIS data, manufacturing firms; low and high tech
Lee et al. (2018)	There is a positive relationship between appropriability mechanisms and product innovation performance (% sales from new products). For high-tech firms, formal and informal mechanism are complements; for low-tech firms, they are substitutes.	Korean Innovation Survey; manufacturing firms; high- and low-tech firms.
Leiponen and Byma (2009)	Product innovation is not associated with importance of appropriation methods. Firms perceive informal means as more important than patenting. Low-tech services prefer speed to market (relative to KIBS). No differences between high- and low-tech manufacturing firms.	Finish small firms; manufacturing (high- v. low-tech); services (KIBS v. low-tech)

Study	Key findings related to appropriation mechanisms and innovation	Sample characteristics
Olander et al. (2014)	Formal appropriation tools aid value capture (commercialising innovation). Informal tools have no impact.	Finish data (no sector information)
Stefan and Bengtsson (2017)	Informal tools increase radical innovation activity. Formal tools have no significant impact.	European Open innovation survey; manufacturing firms
Thomä and Bizer (2013)	Users of informal or formal protection mechanisms are more likely to undertake product innovation. Knowledge-intensive manufacturing firms' higher users of formal or informal tools. Knowledge-intensive services higher informal tools.	German CIS data (small firms); manufacturing and services; knowledge intense vs. other
Xu et al. (2012)	Both formal and informal appropriation tools are associated with higher innovation activity. External knowledge sourcing reduces impact of informal tools but increases impact of formal tools.	Chinse, multi-sector (predominately manufacturing)
Zobel et al. (2017)	Formal appropriation mechanisms are positively related to radical innovation performance (% sales from new-to-market products) but negatively related to incremental innovation performance (% sales from improved or new-to-firm products). No relationship with informal mechanisms. Openness increases use of appropriation mechanisms.	Dutch CIS data; manufacturing

Table 2. Manufacturing descriptive statistics

	Variable	Mean	s.d.	Min	Max	1	2	3	4	5	6	7	8	9
1	Radical Innovation (log)	0.613	1.116	0.00	- [a]									
2	Collaboration Breadth	1.190	1.616	0.00	6.00	0.39**								
3	Formal Appropriability	0.415	0.890	0.00	4.00	0.33**	0.42**							
4	Informal Appropriability	0.447	0.781	0.00	3.00	0.33**	0.47**	0.46**						
5	R&D Intensity	0.011	0.043	0.00	- [a]	0.21**	0.25**	0.26**	0.31**					
6	Number of Employees (log)	4.173	1.394	0.00	- [a]	0.11**	0.26**	0.26**	0.16**	0.05*				
7	Start-up	0.053	0.224	0.00	1.00	0.02†	0.01	-0.04	-0.05*	-0.01	-0.08**			
8	Market Size	2.961	1.078	1.00	4.00	0.20**	0.25**	0.27**	0.28**	0.16**	0.34**	-0.05*		
9	Labour Productivity	176.8	1598.8	- [a]	- [a]	0.04†	0.09**	0.06*	0.03	0.01	0.22	-0.02	0.13	
10	Human Capital	10.3	15.565	0.00	100.00	0.21**	0.28**	0.21**	0.25**	0.24**	0.17**	0.03	0.24**	0.17**

***p ≤ 0.01; *p ≤ 0.05; †p ≤ 0.10; a: numbers suppressed in compliance with ONS rules on data disclosure*

Table 3. Services descriptive statistics

	Variable	Mean	s.d.	Min	Max	1	2	3	4	5	6	7	8	9
1	Radical Innovation (log)	0.147	0.454	0.00	4.62									
2	Collaboration Breadth	0.703	1.377	0.00	6.00	0.32**								
3	Formal Appropriability	0.183	0.568	0.00	4.00	0.22**	0.27**							
4	Informal Appropriability	0.181	0.512	0.00	3.00	0.34**	0.37**	0.46**						
5	R&D Intensity	0.010	0.066	0.00	- [a]	0.20**	0.18**	0.24**	0.29**					
6	Number of Employees (log)	4.041	1.594	0.00	- [a]	-0.01	0.10**	0.07**	0.02†	-0.03				
7	Start-up	0.067	0.250	0.00	1.00	0.05**	0.02	0.00	0.01	-0.01	-0.09**			
8	Market Size	2.015	1.090	1.00	4.00	0.14**	0.17**	0.26**	0.30**	0.17**	0.13**	-0.05**		
9	Labour Productivity	235.7	2632.8	- [a]	- [a]	0.00	0.03	0.00	0.02	-0.01	-0.01**	0.00	0.05**	
10	Human Capital	18.3	27.408	0.00	100.00	0.15**	0.20**	0.22**	0.29**	0.25**	-0.01	0.00	0.36**	0.02**

***p ≤ 0.01; *p ≤ 0.05; †p ≤ 0.10; a: numbers suppressed in compliance with ONS rules on data disclosure*

Table 4. Manufacturing industry averages

Industry	N	Collaboration Breadth (x6)	Formal Appropriability (x4)	Informal Appropriability (x3)	% Radical Innovation
Food, beverage, and tobacco	172	1.22	0.30	0.25	3.33
Textiles, wearing apparel, and leather	83	1..07	0.40	0.22	2.79
Wood, paper, printing, and publising	204	0.71	0.23	0.25	2.17
Petroleum, chemicals, rubber, and plastic	229	1.42	0.56	0.60	3.19
Metals, metallic, and non-metallic mineral	355	0.93	0.31	0.35	2.83
Computer, electric, and elecronic equipment	154	1.74	0.76	0.79	6.98
Machinery and equipment	161	1.47	0.52	0.64	5.22
Transport	133	1.50	0.38	0.58	4.49
Other Manufacturing	204	1.01	0.37	0.39	3.72

Table 5. Service industry averages

Industry	N	Collaboration Breadth (x6)	Formal Appropriability (x4)	Informal Appropriability (x3)	% Radical Innovation
Electricity, Gas, and Water Supply	112	0.84	0.13	0.21	2.40
Construction	747	0.56	0.05	0.10	1.16
Wholesale and Retail Trade	1507	0.61	0.22	0.14	1.99
Transportation	359	0.59	0.07	0.11	1.11
Accommodation and Food Services	595	0.57	0.10	0.07	1.87
Information and Communication	352	1.29	0.48	0.58	4.87
Financial, Insurance, and Real Estate	387	0.79	0.15	0.13	1.36
Professional, Technical, and Scientific	982	0.98	0.33	0.33	4.52
Administration and Support	779	0.52	0.07	0.12	1.74

Table 6. Formal versus informal appropriability for innovation performance and the impact of collaboration breadth

	Innovation Performance									
	Model 0		Model 1		Model 2		Model 3		Model 4	
Variables	Coeff	*Std. Err*	Coeff	*Std. Err*	Coeff	*Std. Err*	Coeff	*Std. Err*	Coeff	*Std. Err*
Collaboration Breadth			0.489***	*0.029*	0.489***	*0.029*	0.589***	*0.038*	0.566***	*0.040*
Formal Appropriability			0.344***	*0.057*	0.258***	*0.077*	0.538***	*0.101*	0.386***	*0.120*
Informal Appropriability			0.542***	*0.067*	0.726***	*0.089*	1.042***	*0.116*	1.058***	*0.134*
Manuf x Formal					0.184†	*0.109*	0.213*	*0.110*	0.570**	*0.183*
Manuf x Informal					-0.398***	*0.124*	-0.380**	*0.128*	-0.412*	*0.205*
Collab x Manuf							0.088	*0.057*	0.159*	*0.069*
Collab x Formal							-0.109***	*0.029*	-0.046	*0.039*
Collab x informal							-0.137***	*0.034*	-0.147***	*0.045*
Collab x Formal x Manuf									-0.139*	*0.058*
Collab x Informal x Manuf									0.015	*0.068*
R&D Intensity	5.417***	*0.684*	1.756**	*0.625*	1.707**	*0.626*	1.919**	*0.618*	1.939**	*0.617*
Nb of Employees (log)	0.058†	*0.033*	-0.076*	*0.031*	-0.075*	*0.031*	-0.066*	*0.031*	-0.065*	*0.031*
Startup	0.684***	*0.185*	0.469**	*0.168*	0.457**	*0.168*	0.445**	*0.168*	0.457**	*0.168*
Market Size	0.470***	*0.049*	0.233***	*0.045*	0.230***	*0.045*	0.204***	*0.045*	0.204***	*0.045*
Labor Productivity	0.000	*0.000*	0.000	*0.000*	0.000	*0.000*	0.000	*0.000*	0.000	*0.000*
Human Capital	0.013***	*0.002*	0.005**	*0.002*	0.004**	*0.002*	0.005**	*0.002*	0.005**	*0.002*
North West	-0.502†	*0.268*	-0.525*	*0.243*	-0.544*	*0.243*	-0.567*	*0.243*	-0.558*	*0.243*
Yorkshire	-0.823**	*0.282*	-0.685**	*0.255*	-0.696**	*0.255*	-0.720**	*0.255*	-0.721**	*0.255*
East Midlands	-0.579*	*0.282*	-0.516*	*0.256*	-0.530*	*0.256*	-0.575*	*0.256*	-0.568*	*0.255*
West Midlands	-0.840**	*0.280*	-0.836***	*0.256*	-0.853***	*0.256*	-0.853***	*0.256*	-0.855***	*0.255*
Eastern	-0.501†	*0.271*	-0.458†	*0.245*	-0.467†	*0.246*	-0.479†	*0.245*	-0.473†	*0.245*
London	-1.135***	*0.271*	-0.898***	*0.245*	-0.909***	*0.246*	-0.942***	*0.245*	-0.926***	*0.245*
South East	-0.488†	*0.257*	-0.434†	*0.233*	-0.450†	*0.233*	-0.472†	*0.233*	-0.464†	*0.232*
South West	-0.521†	*0.278*	-0.518*	*0.252*	-0.521*	*0.253*	-0.547*	*0.252*	-0.533*	*0.252*
Wales	-0.831**	*0.321*	-0.868**	*0.292*	-0.861**	*0.292*	-0.905**	*0.292*	-0.904**	*0.292*
Scotland	-1.006***	*0.294*	-0.806**	*0.266*	-0.825**	*0.266*	-0.810**	*0.266*	-0.801**	*0.265*
Northern Ireland	-1.238***	*0.365*	-1.013**	*0.330*	-1.032**	*0.331*	-1.057**	*0.331*	-1.043**	*0.330*
Manuf Dummy	1.567***	*0.118*	1.086***	*0.107*	1.203***	*0.125*	1.071***	*0.140*	0.955***	*0.153*
High Knowledge	0.164	*0.136*	-0.043	*0.125*	-0.054	*0.125*	-0.097	*0.125*	-0.097	*0.125*
Constant	-4.269***	*0.303*	-3.379***	*0.270*	-3.394***	*0.272*	-3.474***	*0.274*	-3.444***	*0.274*
Chi-Square	733.2		1417.1		1427.5		1488.7		1495.7	
Left Censored	6198		6193		6193		6193		6193	
N	7183		7178		7178		7178		7178	
Log likelihood	-3902.9		-3560.2		-3555.7		-3524.4		-3520.9	
R2	0.0859		0.1666		0.1672		0.1744		0.1752	

**** indicates significance at the 0.1%, ** at the 1%, * at the 5%, and † at the 10%*

Table 7. The impact of knowledge intensity

	Innovation Performance			
	Model 1		Model 2	
Variables	Coeff	*Std. Err*	Coeff	*Std. Err*
Collaboration Breadth	0.466***	*0.031*	0.466***	*0.031*
Formal Appropriability	0.413***	*0.090*	0.399***	*0.097*
Informal Appropriability	0.402***	*0.113*	0.422***	*0.122*
Manuf x Formal	0.106	*0.109*	0.129	*0.128*
Manuf x Informal	-0.165	*0.131*	-0.198	*0.155*
High Knowledge x Manuf	0.282	*0.252*	0.247	*0.335*
High Knowledge x Formal	-0.388**	*0.124*	-0.351*	*0.173*
High Knowledge x Informal	0.276*	*0.143*	0.228	*0.190*
High Knowledge x Formal x Manuf			-0.077	*0.247*
high Knowledge x Informal x Manuf			0.110	*0.286*
R&D Intensity	1.450*	*0.618*	1.451*	*0.618*
Nb of Employees (log)	-0.072*	*0.034*	-0.071*	*0.034*
Startup	0.534**	*0.181*	0.534**	*0.181*
Market Size	0.234***	*0.048*	0.234**	*0.048*
Labor Productivity	0.000	*0.000*	0.000	*0.000*
Human Capital	0.004*	*0.002*	0.004*	*0.002*
North West	-0.492†	*0.267*	-0.494†	*0.267*
Yorkshire	-0.602*	*0.277*	-0.603*	*0.277*
East Midlands	-0.542†	*0.279*	-0.543†	*0.279*
West Midlands	-0.754**	*0.275*	-0.755**	*0.275*
Eastern	-0.408	*0.267*	-0.410	*0.267*
London	-0.752**	*0.272*	-0.753**	*0.272*
South East	-0.325	*0.253*	-0.328	*0.253*
South West	-0.385	*0.274*	-0.387	*0.274*
Wales	-0.721**	*0.310*	-0.722**	*0.310*
Scotland	-0.767**	*0.291*	-0.769**	*0.291*
Northern Ireland	-1.020**	*0.356*	-1.021**	*0.356*
Manuf Dummy	1.017***	*0.131*	1.020***	*0.135*
High Knowledge	-0.043	*0.179*	-0.032	*0.195*
Constant	-3.214***	*0.297*	-3.215***	*0.297*
Chi-Square	1136.1		1136.2	
Left Censored	3511		3511	
N	4355		4355	
Log likelihood	-2919.6		-2919.5	
R2	0.1629		0.1629	

**** indicates significance at the 0.1%, ** at the 1%, * at the 5%, and † at the 10%*

Table 8: Summary of results of hypotheses testing

Hypotheses	Results
Formal versus Informal Appropriability in Manufacturing/Service	
H1a: Formal appropriability has a stronger influence on innovation performance in manufacturing firms than informal appropriability.	*No*
H1b: Informal appropriability has a stronger influence on innovation performance in service firms than formal appropriability.	Yes
Impact of Collaboration Breadth	
H2a: The extent to which collaboration breadth mitigates the effectiveness of appropriability on innovation performance will be greater for informal versus formal mechanisms.	*No*
H2b: The extent to which collaboration breadth mitigates the effectiveness of appropriability on innovation performance will be greater for service firms versus manufacturing firms.	*No*
Impact of Knowledge-Intensity	
H3: The relative impact of informal (versus formal) appropriability on innovation performance will be increased for knowledge-intensive firms	Yes
H4a: In less knowledge-intensive manufacturing firms, formal appropriability has a stronger influence on innovation performance than informal appropriability.	Yes
H4b: In high knowledge-intensive service firms, informal appropriability has a stronger influence on innovation performance than formal appropriability	Yes

Table 9. Post hoc analysis: the impact of knowledge intensity and collaboration

	Manufacturing Firms								Services Firms							
	Innovation Performance								Innovation Performance							
	High Knowledge Intensive				Low Knowledge Intensive				High Knowledge Intensive				Low Knowledge Intensive			
	Model 1		Model 2		Model 1		Model 2		Model 1		Model 2		Model 1		Model 2	
Variables	Coeff	*Std. Err*	Coeff	*Std. Err*	Coeff	*Std. Err*	Coeff	*Std. Err*	Coeff	*Std. Err*	Coeff	*Std. Err*	Coeff	*Std. Err*	Coeff	
Collaboration Breadth	0.435***	*0.094*	0.665***	*0.126*	0.644***	*0.113*	0.906***	*0.135*	0.230***	*0.042*	0.307***	*0.055*	0.377***	*0.038*	0.431***	
Formal Appropriability	0.256	*0.142*	0.834***	*0.249*	0.591**	*0.191*	0.912**	*0.321*	0.112	*0.080*	0.126	*0.136*	0.312***	*0.077*	0.394***	
Informal Appropriability	0.419**	*0.167*	0.595*	*0.273*	0.465	*0.256*	1.306**	*0.427*	0.575***	*0.094*	0.790***	*0.146*	0.258*	*0.104*	0.546***	
Collaboration x Formal			-0.198**	*0.071*			-0.122	*0.103*			0.002	*0.041*			-0.032	
Collaboration x Informal			-0.070	*0.084*			-0.373*	*0.150*			-0.100*	*0.050*			-0.118*	
R&D Intensity	-0.995	*2.010*	-0.351	*1.976*	13.739	*8.020*	11.348	*7.842*	1.648***	*0.477*	1.620***	*0.477*	0.861	*1.446*	1.093	
Nb of Employees (log)	-0.142	*0.122*	-0.148	*0.121*	0.056	*0.127*	0.065	*0.125*	0.073	*0.049*	0.084	*0.049*	-0.107**	*0.038*	-0.105**	
Startup	0.691	*0.694*	0.808	*0.687*	-0.141	*0.630*	-0.141	*0.628*	0.220	*0.272*	0.232	*0.275*	0.391*	*0.188*	0.384*	
Market Size	0.227	*0.216*	0.201	*0.215*	0.044	*0.171*	0.038	*0.170*	0.052	*0.065*	0.035	*0.066*	0.184***	*0.053*	0.173***	
Labor Productivity	0.001	*0.001*	0.001	*0.001*	-0.001	*0.002*	-0.001	*0.002*	0.000	*0.000*	0.000	*0.000*	0.000	*0.000*	0.000	
Human Capital	0.015	*0.008*	0.016*	*0.008*	0.009	*0.014*	0.009	*0.014*	0.003	*0.002*	0.003	*0.002*	0.007**	*0.003*	0.008**	
North West	-0.232	*1.069*	-0.287	*1.059*	-0.549	*0.806*	-0.637	*0.788*	-0.484	*0.377*	-0.511	*0.381*	-0.552	*0.310*	-0.552	
Yorkshire	-0.172	*1.081*	-0.187	*1.070*	-0.346	*0.830*	-0.537	*0.817*	-0.484	*0.389*	-0.475	*0.392*	-0.774*	*0.338*	-0.775*	
East Midlands	-0.063	*1.100*	-0.083	*1.092*	-0.580	*0.840*	-0.691	*0.824*	-0.618	*0.408*	-0.627	*0.412*	-0.450	*0.321*	-0.489	
West Midlands	-1.220	*1.107*	-1.142	*1.095*	-0.464	*0.896*	-0.774	*0.892*	-0.868*	*0.424*	-0.921*	*0.431*	-0.780*	*0.330*	-0.775*	
Eastern	0.718	*1.053*	0.686	*1.047*	-0.990	*0.931*	-1.014	*0.913*	-0.356	*0.363*	-0.327	*0.366*	-0.490	*0.310*	-0.466	
London	1.119	*1.202*	1.056	*1.194*	-0.176	*0.990*	-0.390	*0.983*	-0.677*	*0.343*	-0.665	*0.345*	-0.708	*0.303*	-0.739*	
South East	-0.080	*1.053*	-0.131	*1.044*	0.188	*0.826*	0.010	*0.811*	-0.524	*0.347*	-0.506	*0.350*	-0.394	*0.287*	-0.424	
South West	0.758	*1.085*	0.870	*1.070*	0.011	*0.867*	-0.236	*0.851*	-0.805*	*0.395*	-0.822*	*0.399*	-0.403	*0.310*	-0.437	
Wales	0.297	*1.155*	0.210	*1.148*	1.088	*0.890*	1.008	*0.868*	-1.125*	*0.522*	-1.120*	*0.532*	-1.290**	*0.422*	-1.302**	
Scotland	-1.014	*1.209*	-0.780	*1.193*	-0.255	*0.862*	-0.304	*0.842*	-0.534	*0.379*	-0.513	*0.382*	-0.540	*0.330*	-0.542	
Northern Ireland	-1.618	*1.619*	-1.707	*1.611*	-1.352	*1.145*	-1.489	*1.142*	-1.417*	*0.592*	-1.512*	*0.608*	-0.803*	*0.396*	-0.814*	
Constant	-2.519	*1.331*	-2.886*	*1.331*	-3.013**	*0.947*	-3.248***	*0.940*	-2.032***	*0.412*	-2.148***	*0.421*	-1.811***	*0.325*	-1.851***	
Chi-Square	111.2		122.7		133.5		149.3		252.7		258.0		336.1		347.8	
Left Censored	257		257		435		435		912		912		2046		2046	
N	405		405		565		565		1092		1092		2293		2293	
Log likelihood	-457.9		-452.2		-459.3		-451.4		-540.5		-537.8		-840.8		-835.0	
R2	0.1083		0.1195		0.1269		0.1419		0.1895		0.193		0.1666		0.1724	
F-Test for R2 Change	4.67***		5.61**		5.00***		7.57***		8.33***		2.58*		10.24***		5.70**	

**** p ≤ 0.001; ** p ≤ 0.01; * p ≤ 0.05*

Figure 1. Conceptual model.

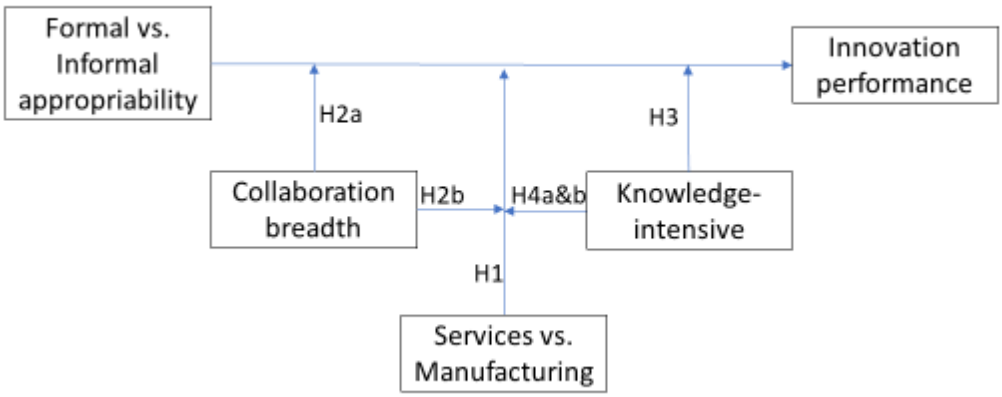
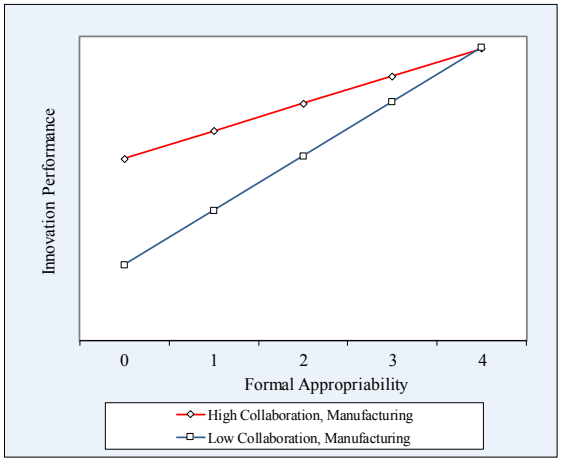
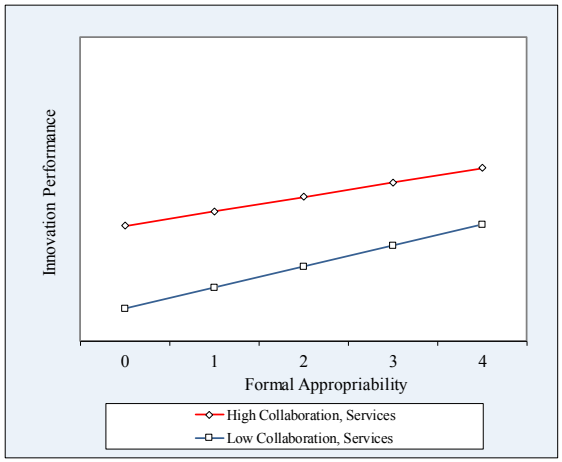


Figure 2. Moderating effect of collaboration on the relationship between appropriability and innovation performance

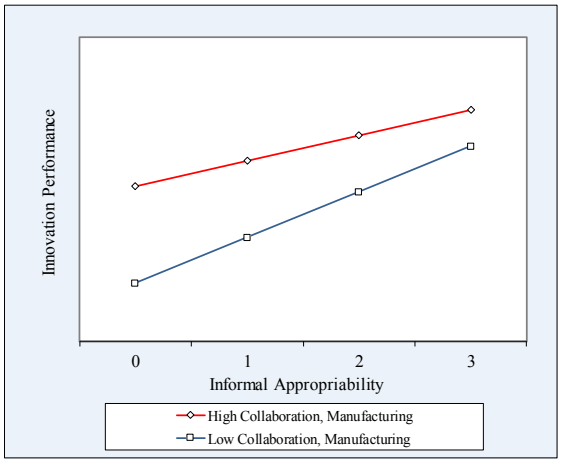
A. Formal appropriability – manufacturing firms



B. Formal appropriability – service firms



C. Informal appropriability – manufacturing firms



D. Informal appropriability – service firms

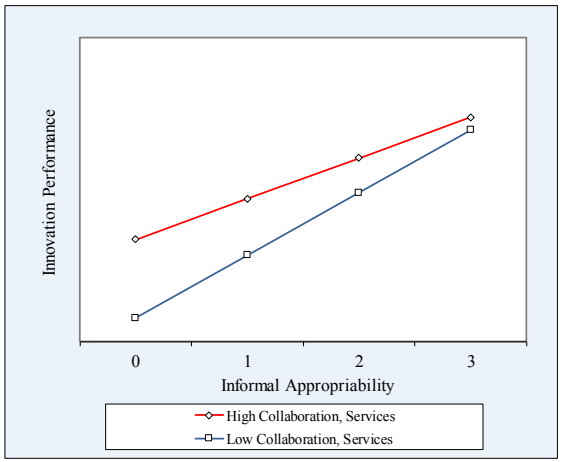
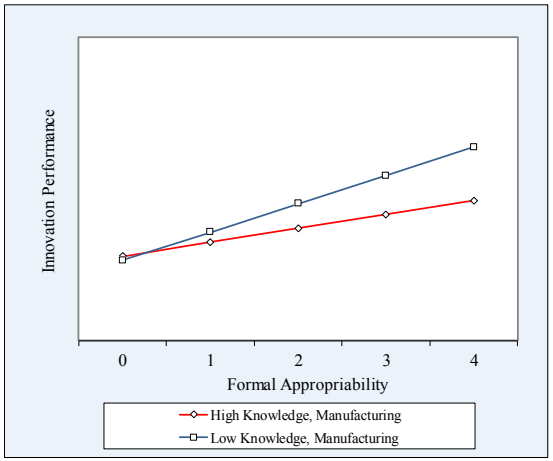
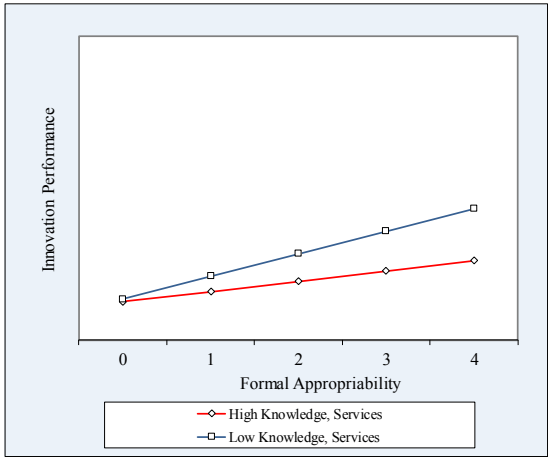


Figure 3. Moderating effect of knowledge intensity on the relationship between appropriability and innovation performance

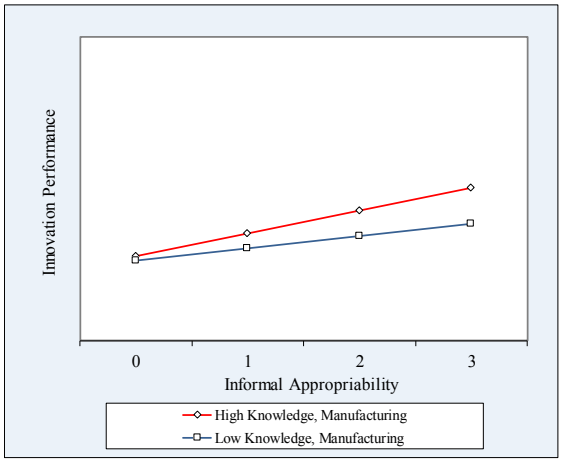
A. Formal appropriability – manufacturing firms



B. Formal appropriability – service firms



C. Informal appropriability – manufacturing firms



D. Informal appropriability – service firms