COMPLEMENTARITIES IN THE SOURCING, USE AND EXPLOITATION OF MANAGERIAL AND TECHNOLOGICAL INNOVATIONS

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Abstract

This paper is primarily concerned with how managerial and technological innovations interact, and their relationship with firm performance. Parallels between managerial innovations and investments in intangibles are highlighted. Using an existing data set relating to 1497 UK enterprises in 2009 with an emphasis upon the service sector, it is shown that firms both source and use managerial and technological innovations and different types thereof simultaneously, suggesting widespread complementarities. Factor analysis is used to generate combined indicators of firms' overall efforts in both sourcing and using different innovations and enables their allocation to clusters. The most active sourcing and using clusters are the smallest, whilst the least active are the largest. Firm characteristics differ across both sourcing and using clusters in expected ways. Further, (i) there is a positive relationship between corporate performance and the intensity of both sourcing and using innovations, and (ii) firms undertaking technological (managerial) innovation experience greater improvement in sales growth if they also undertake managerial (technological) innovation. The findings indicate that reliance upon either managerial or technological indicators of innovation alone could be misleading in terms of both measuring the extent of innovation and the impacts of different types of innovation upon firm performance.

Key Words: Managerial innovation; technological innovation; innovation stages; intangibles, complementarities; firm performance.

JEL classification: O3

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1. INTRODUCTION

Innovation is a multidimensional phenomenon that (as clearly specified in various editions of the Oslo manual, e.g., OECD, 2018 and OECD, 2006) involves managerial or organisational activities such as changes in marketing methods, business practices, workplace organisation or external relations as well as the more commonly studied dimensions involving technological activities such as R&D or product and process innovation. We argue that the distinction between managerial/organisational innovations and technological innovations maps closely into recent work upon the classification of intangible and tangible assets and their respective roles in the determination of firm performance (Haskel & Westlake, 2017, and Riley & Bondibene, 2018). The aims of this paper are to conceptually and empirically explore: (i) patterns of managerial and technological innovation and how they interact; (ii) the determinants of such patterns; and (iii) how firm performance relates to the innovation patterns identified[1].

In contrast to the extensive literature in the management field that uses case study methods to explore managerial innovations and their impacts upon firm performance[2], this paper follows the methods employed in a series of economics-based contributions by Bloom & Van Reenen

[1] The approach pursued here exploring interrelationships between managerial and technological innovations and impacts upon firm performance, differs from, although aligns with, a significant literature that argues that the success of (or return to) technological innovations is at least partly attributable to 'good' management practice (for example, Bartoloni & Baussola, 2015; Anon-Higon et, al. 2017; Nemlioglu & Mallick, 2017; Sadun & Van Reenen, 2005; Bartz-Zuccala et al., 2018).

[2] One might note however that Ruigrok et al. (1999) using international data is a good early example of the use of a quantitative survey-based methodology in the management field.

(2007, 2010), for an international sample, and Bloom et. al. (2013), for the US, that have used quantitative techniques applied to large (survey) data sets to illustrate the adoption of identified management practices[3] and explore links to firm performance[4]. The paper builds upon a previous study by the current authors, Battisti and Stoneman (2010), which used data from the UK Community Innovation Survey (CIS4) to explore managerial and technological innovations and their interactions. The current work uses a similar approach to that previously employed but uses data that comes from an enterprise level survey of innovation activities of 1497 firms in the UK undertaken for the National Endowment for the Science Technology and the Arts, NESTA, (see Roper et. al., 2009, for details and an initial exploratory investigation from a different standpoint). This dataset, in addition to availability has two main advantages.

The first advantage is that the dataset has a very obvious and deliberate bias towards the service sector with six of the nine industries in the chosen sample being considered service industries (with the three others being automotive i.e., in manufacturing, energy production and construction). Although there is equal interest in the performance of companies in all sectors (see, for example, O'Mahony & De Boer 2002, Griffith et. al. 2003, Griffith & Harmgart 2005) and the service sector is now the largest sector in the UK economy, our knowledge of, and empirical evidence on, service innovation dynamics and performance are still quite limited (Battisti et. al. 2013, Hall et. al. 2009, Gallouj & Weinstein, 1997). The sample employed by Battisti and Stoneman (2010) using data from the Community Innovation Survey (CIS4) does contain a limited number of service sector firms. However,

[3] The papers isolate a number of different management practices (eighteen in Bloom and Van Reenen, 2010) encompassing monitoring, targets and incentives, which represent best practice in the sense that a firm that has adopted the practice will, on average, increase their productivity. We consider these practices to be managerial innovations although they are not so labelled by the original authors.

[4] This is a welcome move away from the traditional reliance on R&D and patent indicators as proxies for, or measures of, innovative activity, which approach ignores the complexity and the multifaceted nature of the innovation process (Hall et. al. 2009, Haskel & Pensole, 2009)

the samples used by Bloom & Van Reenen (2007, 2010) & Bloom et.al. (2013) are restricted to the manufacturing sector.

The second advantage of the data employed is that innovation is considered as a multi-stage process, involving sourcing, introduction and exploitation. This provides a rich tapestry for the analysis and enables exploration not only of managerial and technological innovation at each of the three different stages but also of potential linkages across the stages of the innovation process.

Following Battisti & Stoneman (2010), taking a multi-dimensional approach, it is here argued that managerial, product and process innovation are three different but equal facets of innovation per se, and should be considered in equal or similar ways. Bloom & Van Reenen (2010), on the other hand, consider managerial innovation as a determinant of firm performance and technological innovation as an aspect of firm performance[5]. For example, they treat as reflections of a relation between innovation and corporate performance that establishments that score more highly in the adoption of the management practices identified also appear to show higher R&D spending and number of patents applied for. In our approach, any observation that managerial innovation and product and process innovation tend to be positively related is instead to be considered as potentially a reflection of complementarities in the innovation process across different types of innovation (an issue also explored in Mol & Birkinshaw, 2009 and Frenz & Lambert, 2008b).

[5] For example, in Bloom and Van Reenen (2007) they talk instead of whether "whether the management measure was proxying for better technology in the firm".

Following Battisti & Stoneman (2010), in this paper the main empirical technique employed is Iterated Principal Factor Analysis (IPFA). We look at different innovation activities, both managerial and technological, and note considerable correlation between the simultaneous pursuit of these different activities. We further isolate a smaller number of principal factors within which the several innovation activities of firms are weighted and via which they might be aggregated, thereby enabling identification of clusters of firms with different innovation patterns which may be used to explore the relation between innovation of all types and firm performance. On the other hand, Bloom & Van Reenen (2010), isolate eighteen different management practices with use of each measured on a scale from 1 to 5 and the main management (innovation) indicator employed in their performance analyses is the simple average of these scores over all 18 practices. Higher scores are interpreted as better management (Bloom & Van Reenen, 2007). Thus, the practices are not weighted and each is considered as important as any other[6]. Although Bloom & Van Reenen (2007) report also using factor analysis and employing the primary factor from such analysis to provide weights for the measure of the overall employment of management practices, this impacted only marginally upon their results and the technique is not emphasised.

In the next section more detail is provided upon; the definitions of types of innovation and the stages in the innovation process; potential complementarities in the innovation process; the theoretical lens on which the exploration of the data is based; and potential determinants of the extent of innovative activity. Section 3 provides some detail on the origins and structure of the sample data and presents some basic findings upon the sourcing and use of different innovation types. Section 4 discusses patterns of cross type complementarities, and presents

[6] Bloom & Van Reenen (2007) also report upon the use of data on individual management practices but this impacted only marginally upon their results re management and performance.

the results on overall patterns of sourcing and use, taking account, via the use of IPFA, of synergies/complementarities across types and stages in the innovation process. The relation of the extent of innovation in firms to firm characteristics is detailed in a separate Appendix to maintain the flow of the main argument. In section 5 we relate firm performance to innovation activity. Section 6 presents conclusions and implications.

2. CONCEPTUAL FRAMEWORK

There are many definitions of innovation that have been proposed and employed in the literature. Business innovation is defined in the 2018 edition of the Oslo manual (OECD/Eurostat, 2018) thus:

A business innovation is a new or improved product or business process (or combination thereof) that differs significantly from the firm's previous products or business processes and that has been introduced on the market or brought into use by the firm (p. 20).

It is stated however in OECD/Eurostat (2018), that although different from the definition in earlier editions of the Oslo manual this definition encompasses the same activities as defined in earlier editions. In OECD (2006, p. 24) innovative activity by a firm is defined to involve 'a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations.' We thus recognise here that innovation must also be considered to relate to changes in organisation, management methods (see, for example Mol & Birkinshaw, 2009) and customer and supplier relationships and cannot be simply constrained to technological process or product innovation. In fact, non-technological innovations may be especially crucial in service-orientated industries (and perhaps in other industries experiencing servitisation, see Vandermerwe & Rada 1988, Neely, 2008, 2009 and Baines et al. 2009),

where products are intangible and heterogeneous and innovative activity does not necessarily take place in formalised R&D laboratories or make use of traditional intellectual property protection rights (see Tether & Hipp, 2002, Hall et. al. 2009, Haskel & Pensole, 2009). We consider that the definition of innovation will encompass both hard (functional) and soft (aesthetic) innovations (see Stoneman, 2010).

Following Roper et. al. (2008) the innovation process thus defined can be considered to involve three stages: (i) the sourcing of innovations; (ii) the introduction of innovations; and (iii) the exploitation of innovations to generate improvements in corporate performance. Five particular sourcing activities are here defined and measured, each of which reflects a means by which firms may acquire technological or managerial knowledge: engaging in activities relating to R&D; engaging in activities related to design; engaging in changes to business processes (considered to be synonymous with process innovation as usually defined); sourcing new equipment and software; and new branding and marketing activity.

There has been considerable emphasis in recent research upon the role of intangibles in the measurement and determination of firm performance. Riley & Bondibene (2018) divide intangibles into three main categories: innovative property; digitized information and economic competences or organizational capital, which they measure respectively by information on R&D investments, and investment in software and databases; and advertising and marketing purchases. The sourcing activities that we analyse map quite neatly in to this framework with: engaging in activities relating to R&D and design being (probably a better) indicator of innovative property; sourcing new equipment and software matching digitized information; and new branding and marketing activity being the equivalent of advertising and

marketing purchases. Our other sourcing activity i.e. engaging in changes to business processes may be considered as relating to tangible rather than intangible investments.

The actual sources of innovations, inter alia, may be: legitimate (from the market) or illegitimate (stolen); generated in house or bought in (thus allowing open innovation); or come built in to new capital goods or embodied in new members of the workforce.

In line with the OECD (2006) definition of innovation, the use stage of innovative activity is here defined and measured as involving some or all of the following six activities: introducing new or significantly improved products or services; making significant changes to business processes; implementing a new or significantly changed corporate strategy; implementing advanced management techniques; implementing major changes to organizational structure; and implementing changes in marketing concepts or strategies. In terms of the Riley & Bondibene (2018) classification, the first two of these would clearly map into investment in tangible capital whereas the others would map into investments in intangible capital and, in particular, organizational capital and economic competences. This division we find reappears as important when we analyse the data below, causing us to identify two main classes of innovative activity which we label managerial and technological innovation.

We note that any relationship between generating, introducing and using innovations may be multidirectional. One may, for example, argue that either (i) the prospect of gain from introduction induces a firm to search for or source knowledge, or (ii) the acquisition or sourcing of knowledge induces a firm to introduce or use that knowledge. Thus, for example, a firm may well wish to introduce a new product but to do so will need to source knowledge

via development and or design of that product and or establish an organisational structure that will optimise the launching process. Alternatively, a firm may be approached by a capital good supplier with knowledge of a new process which then leads it to introduce a new production technology.

With the exception of Mol & Birkenshaw (2009), few previous studies of innovation have attempted to jointly explore the source and use stages of innovation. Thus, in addition to allowing there to be different stages in the innovation process we explore potential complementarities across the stages. However, although one may confidently predict that the sourcing and introduction of innovations will be positively correlated or complementary, even if only on the grounds that, ceteris paribus, more use implies greater need to source and more sourcing implies more innovations available for use, one may say nothing a priori of the directions of causality in that relationship.

Different innovations may also be complementary i.e. the undertaking of one may raise the marginal payoff of undertaking the other (Battisti & Stoneman, 2010). For example, launching new products may be more successful if accompanied with marketing innovations (Bartoloni & Baussola, 2015) and thus one may expect to see marketing and product innovations side by side. Similarly, firms may undertake both R&D and Design activities in the development of a new product in the hope that the resultant advance will be more appealing to the market. A number of studies argue and present evidence that such complementarities exist. Examples are the study of internal and external sources of knowledge acquisition in relation to firm strategy (e.g. Cassiman & Veugelers, 2002, Arora & Gambardella 1994); studies of the impact of the use of different management practices on firm performance and productivity (Ichniowski et al. 1997, Whittington et al. 1999, Ruigrok

et al. 1999, Huselid, 1995, Battisti & Iona, 2009); and other studies of the joint use of technological and management innovations (Black & Lynch 2004, Bresnahan et al 2002, Brynjolfsson et al 2002, Milgrom & Roberts 1990, Frenz & Lambert, 2008a, 2009; and Brynjolfsson & Saunders, 2009; Anon-Higon et, al. 2017; PedroTorres & Augusta, 2019). Thus, in addition to allowing for different types of innovations, we explore potential complementarities across the types.

The third stage in the innovation process (exploitation) concerns the relationship between firm performance and the sourcing and adoption of innovations. A vast economic and management literature has looked at the impact of innovation on firm performance (see for surveys Hall & Oriani, 2006, or Hall, 2000). Although it is generally found that the most profitable companies and those that grow faster are those that innovate (Roper et. al. 2009, Geroski & Toker, 1996 and Geroski & Machin, 1992) the findings are very noisy and subject to a high degree of heterogeneity (Cefis & Orsenigo, 2001) in terms of the definition and measurement of both innovation and performance. While some studies focus on performance and knowledge sourcing (see for example Leiponen & Helfat, 2005, Cassiman & Veugelers, 2002) others focus on performance and the use of innovations (e.g. Stoneman & Kwon, 1996).

Here we attempt to relate performance to both the sourcing and use of innovations. In our empirical analysis the existence of complementarities across types and stages of innovation play a central role. However, with a data sample that is a single cross section we cannot claim to do any more than isolate relationships between innovation and performance. Causality cannot be deduced from such data. In fact, there is also considerable theoretical argument over the causal direction of the relationship between innovation and firm performance (Hall

et. al., 2009, Frantzen, 2003, Rouvinen, 2002, Lööf & Heshmati, 2004) in that, although innovation may be related to improved performance one cannot say whether, (i) improvements in performance act as the incentive to innovate, or (ii) good performance provides the necessary funding to enable innovation, or (iii) both. Although firms are here assumed to be profit-seeking we do not have measures of changes in profitability, thus, in the empirical analysis we concentrate on sales growth as a measure of performance (a measure also used by Bloom & Van Reenen, 2007).

Our main behavioural assumption is that firms are profit seeking and thus any attempt to seek insight in to the determinants of the sourcing and use of new technology must be based, at least to some degree, upon what determines how expected costs of, payoffs to, and resources available for innovative activity will vary across firms. Pursuing the three stages of innovation approach, we consider that in the sourcing stage firms will be searching for innovations that when introduced will generate gross returns (relative to a counterfactual) over and above the costs of implementation. These searches may be stimulated either by market needs or by internally or externally driven additions to the knowledge base of the firm. The searching or sourcing process will require resources to cover, for example, employment of R&D or design personnel, the employment of consultants, collaboration with universities or management training.

The movement from the sourcing stage to the use stage will involve choices. Of innovations sourced only those that offer an expected positive net return will be pursued further. The costs that are involved in the introduction or use of new technologies may involve the firms, for example, in the purchase of new capital equipment, changes in management and organisational structure, retraining and/or employee relations. Resources will be required and

introduction will involve investment by the firm. Of the innovations introduced, only some may be successful in terms of generating revenues in excess of costs. Success may well be related to, for example, how well the introduction and exploitation of the new technologies are managed, the extent of worker involvement, the characteristics of the markets and the behaviour of competitive rivals.

Based upon these arguments, the variables that are then likely to more closely relate to the extent and direction of innovative activity will include: technological characteristics of products and markets so that, for example, the proportion of firms undertaking formal R&D may be low in service industries such as accountancy, whereas firms in accountancy may be more active when it comes to software acquisition. Such variables (technological characteristics of products and market structure, for example), may be empirically reflected in industry dummies.

Firm characteristics, capabilities, experience and absorptive capacities (see Teece et. al., 1997, Cohen & Levinthal, 1989, Kyrgidou & Spyropoulou, 2012) may also matter, in that the more capable firms will be more innovative. In addition, firm ownership and market structure (Bloom & Van Reenen, 2010) reflecting differing pressures to generate profits via innovation could be influential. In line with the literature, we have thus explored the relationships between the sourcing and use of innovations and a number of firm characteristics. In order to prioritise matters relating to interactions between managerial and technological innovation the details and results relating to firm characteristics are provided in an Appendix rather than the main text.

3. THE INNOVATION SURVEY, BASIC DATA AND INITIAL FINDINGS

The data employed in this paper comes from an enterprise level survey of innovation activities of firms in the UK undertaken for the National Endowment for the Science Technology and the Arts, NESTA, (see Roper et. al., 2009, for details of the design and execution of the survey, representativeness, and an initial exploratory investigation from a different standpoint). The main survey fieldwork was conducted between early June and mid-August 2009 with all survey questions relating to activities in the three years prior to the survey date. Although more recent data would have been preferable[7] much of the current literature is based on data from around the same date or earlier and this source has not been previously used to consider the matters addressed here. Additional longtitudinal data would also have been an advantage. However, although it had been the original intention to do so, the survey has not been repeated and only this single cross section is thus available[8].

Response rates in the survey in the majority of sectors were around 15 per cent with a total of 1,497 usable responses. This is sufficient to provide statistical robustness to our findings. Table 1 details the composition by sector and firm size of the survey responses. Six of the nine industries in the chosen sample may be considered service industries and contribute 77%

[7] It has been suggested to us that digitisation during the period since the survey could affect the current relevance of any findings based on this data. We have no evidence of that. Digitisation or computerisation is a process that has been going on for nearly 70 years, and, although the embodiment of those advances and the nature of the 'best' management techniques may have changed alongside the digital changes, we have no reason to accept an argument that says that the relationship between managerial and technological innovations has been fundamentally altered over the last decade. There is an additional argument (Nambisan et. al. 2019; OECD, 2018) that there is a batch of new digital technologies encompassing AI, e-data, big data, machine learning and the internet of things) that will in the near future lead to a disruption of business and/or changed social and business models. We do not wish to argue against that but we consider that there will still be links (perhaps different links) between managerial or organisational and technological innovations in the future.

[8] A further source of data on the uptake of management practices in British production and services industries is the Management and Expectations Survey (MES) carried out in 2017 by the Office for National Statistics (ONS) and developed as a follow up of the 2016 pilot Management Practice Survey (MPS). The MES questionnaire covers a broader and slightly modified set of questions than the MPS and the UKIS and it was designed to align to the Management and Organisational Practice Survey (MOPS) conducted by the US Census Bureau. Despite being one of the few surveys on the adoption of management practices it contains limited information on non-management innovations and general company characteristics. https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/labourproductivity/articles/experimentaldataonthemanagementpracticesofmanufacturingbusinessesingreatbritain/2018-04-06

of the sample firms (with energy production, construction and automotive comprising the balance of the sample). Small firms (5 – 19 employees) represent 49% of the sample, 20% are large firms (100+ employees) with the balance being medium sized firms.

Table 1. Survey responses by sector and firm size.

Sector (SIC, 2003)	Small (5 – 19 employees)	Medium (20 – 99 employees	Large (100+ employees)	All
Accountancy (74.12)	99	72	21	192
Architectural services (74.2)	95	68	54	217
Automotive (34.3)	29	15	17	61
Construction (45)	84	66	44	194
Consultancy services (74.14)	93	57	40	190
Energy production (23.2, 40.1, 40.2)	44	23	24	91
Legal services (74.11)	69	54	55	178
Software and IT services (72.2 – 72.4)	75	67	47	189
Specialist design (74.87/2)	147	32	6	185
Total	735 (49%)	454 (31%)	308 (20%)	1497

The response rate to questions in the survey that asked for details of expenditure on sourcing and use activities was very poor, and we thus explore sourcing and use via other questions that asked whether firms have been engaged (yes or no) in the different types of sourcing

activities listed above in the three years prior to the survey. There were 1406 usable responses. Table 2 shows the proportion of firms undertaking each type of sourcing. We observe that between one fifth and one half of firms have engaged in each of the different sourcing activities. Although addressed more formally below, the data patterns clearly indicate that the proportion of firms that have reported having sourced any of the five types of innovation varies considerably by type and by industry.

The most frequently observed activities concern the sourcing of new software, and branding and marketing activity, in both of which about half of the firms in the sample have been active. Only 21% of the sample reported having engaged in R&D activities. The share undertaking R&D is lowest in industries such as accountancy, 6%, and legal services, 10%. Firms in accountancy and legal services are more active in software acquisition and branding. This is unsurprising for research in services is not carried out in formal R&D labs as it might be in, for example, traditional manufacturing. Given that, a priori, no one type of sourcing activity is dominant in all sectors, it is clear that in judging the innovativeness of (firms in) different sectors it is necessary to take account of multiple sourcing activities (both technological and managerial) and reliance upon any one indicator alone as the sole, or best, indicator of innovative activity could give a misleading or at least very incomplete picture.

Table 2. Percentage of sample firms sourcing innovation by activity and sector.

	Engage in R&D	Engage in design	Source new business processes	Source new software	Source new branding and marketing
Accountancy	6	22	21	57	46
Architectural services	30	35	39	58	46
Automotive	20	39	48	41	40
Construction	16	21	23	38	51
Consultancy services	24	46	38	50	56
Energy production	34	32	36	41	52
Legal services	10	25	32	42	60
Software and IT services	38	51	41	55	50
Specialist design	18	32	40	63	60
All	21	33	34	51	52

We measure the use or introduction of the different innovation types by dichotomous variables indicating whether, in the three years prior to the survey, firms have undertaken any of the six different activities detailed above. The usable sample is 1497 firms. The pattern of innovation types introduced is detailed in Table 3. On average just above a third of the sample firms (36%) have actively engaged in the introduction of these innovations. The highest intensities of use by type, are of new products/services (47% of the sample), new marketing techniques (45%) and new organisational structures (36%).

Table 3. Use of innovations, by type and industry (% of firms)

Type Sector (number of firms)	Introduced new product /service	Introduced new business process	Introduced new strategy	Introduced new management techniques	Introduced new organization structure	Implemented changes in marketing concepts/ strategies
Accountancy services (192)	31	21	18	17	18	33
Architectural services (217)	48	39	28	28	39	40
Automotive (61)	66	4 8	28	23	32	40
Construction (194)	35	23	27	29	31	37
Consultancy services (190)	54	38	45	34	48	55
Energy production (91)	47	36	33	31	36	40
Legal services (178)	37	32	28	30	33	46
Software & IT services (189)	70	41	43	34	47	54
Specialist design (185)	50	40	31	20	36	54
All (1497)	47	34	31	27	36	45

The pattern of adoption of innovations across industries is heterogeneous. Consultancy services and software /IT services show the highest adoption rates across the spectrum of innovative activities (all the six use categories have been adopted by about 50% of the sample firms). The lowest overall intensity is shown by accountancy services. Although new products and processes are most prevalent in the architecture, automotive, energy production, specialist design and the software/IT sectors, it is new marketing that is most observed in accountancy, construction, consultancy and legal services. These patterns of use clearly

indicate that reliance upon a measure of any one type of using activity could give a misleading picture of total innovative activity across different firms and industries.

4. COMPLEMENTARITIES IN SOURCING AND USING INNOVATIONS

The data in Tables 2 and 3 are useful in indicating the extent to which different sourcing and using activities can be found in the sample of firms. Here we explore the extent to which firms are simultaneously sourcing and using multiple types of innovation. Initial analysis of the sourcing of different innovations across firms revealed that calculated tetrachoric correlation coefficients in the sourcing of pairs of technologies are all positive and significantly different from zero. The data indicates, for example, that of all firms that do R&D, 54% also do design and that of all firms that source new software, 35% also source new business processes. Thus, firms tend simultaneously to source a number of different innovation types.

We also observe that firms are inclined to introduce or use more than one innovation at a time with tetrachoric correlations all positive and significantly different from zero, indicating significant pair wise correlations in the use of different innovation types. For example, more than 50% of the firms that: (i) introduce new products and services also introduce new business processes; (ii) introduce new strategies also introduce new business processes; (iii) introduce new organisational methods also introduce new management methods; and (iv) introduce new marketing techniques also introduce new strategy, management and organisational techniques.

The observation of significant pair wise correlations in both the sourcing and use of different innovations by firms suggests that the different types of innovations may exhibit synergies in sourcing or use and thus be complementary. However, to observe that different types of innovation are simultaneously sourced or introduced is not, of itself, sufficient for complementarities to exist, for the correlation may be spurious and the result of other, third party, factors (such as economic conditions) that create the appearance of complementarity. There are several approaches that can be used to address this issue. Milgrom & Roberts (1990), and Love & Roper (2009), use a supermodularity approach, Van Biesebroeck (2007) offers an instrumental variable approach and Miravete & Pernias (2006) offer a panel data approach. Because it is easy to implement and we only have a single cross section, we follow Battisti & Stoneman (2010) and use the method recommended by Arora & Gambardella (1991) who suggest controlling for unobserved heterogeneity and lurking factors by testing the significance of the correlations of the residuals from probit models for each sourcing and using type that control for a number of covariates.

We have estimated probit models on the sourcing data controlling (the rationales being as in the Appendix) for the age of the business, the number of employees, the industry sector, and whether or not the firm is: part of a group; UK owned; has at least 20% of its employees with a degree; and is export oriented[9]. All coefficients in the Kendall-tau correlation matrix of the residuals of the estimates, which indicates any remaining correlations between sourcing activities, are positive and significantly different from zero with values between 24% (R&D and design) and 3.9% (between R&D and branding and marketing)[10].

[9] Detailed results are available from the corresponding author upon request

[10] A by-product of applying the Arora & Gambardella (1991) approach is some indication of which firm characteristics are likely to be associated with greater sourcing of each of the different types of innovations, however very few of the coefficient estimates were found to be statistically significant.

We also apply the Arora & Gambardella (1991) approach to the data on the use of innovations[11], testing the significance of the correlations of the residuals from the probit estimates of the conditional probabilities to use the different innovations. All the coefficients are significant and positive[12]. The off diagonal correlations vary from 35% (between new product/service and new management technique) and 74% (between new management technique and new organisational structure). These results indicate that there exist strong complementarities in the both the sourcing and use of different innovation types .

The existence of such complementarities suggest that it would be inappropriate to measure the overall sourcing or use of innovations simply by calculating for each firm the total number of sources or uses undertaken (as in Bloom & Van Reenen, 2010). Instead, we perform iterated principal factor analysis (IPFA) based upon the decomposition of the tetrachoric correlation matrix of the pair wise sourcing and using decisions, which allows for any complementarities or synergies in the sourcing and use of new technologies that extend beyond pair wise comparisons. This approach allows identification of the underlying patterns without imposing any particular model or a priori structure. A firm's scores on any principal factor(s) identified may then be used to measure the overall sourcing or using activity of that firm. The principal factors in essence provide a weighting for each of the sourcing or using activity types.

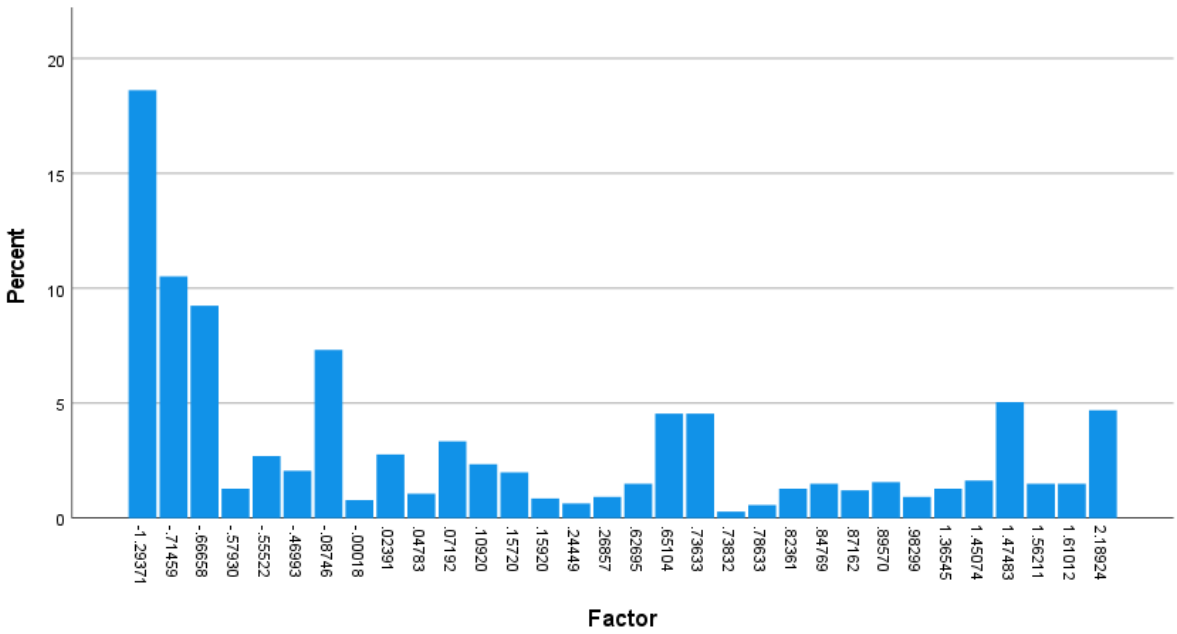
4.1 The sourcing of innovations

[11] Full details are available from the corresponding author upon request.
[12] The Arora & Gambardella (1991) approach also indicates that employment, membership of a group, export orientation, and to some degree a more highly qualified workforce (except for new strategies and new management techniques) all impact positively and significantly on each of the indicators of the use of innovations.

Iterated principal factor analysis (IPFA) based upon the decomposition of the tetrachoric correlation matrix of the pair wise sourcing decision for the firms in the sample has led to the identification of just one factor (labelled FACTOR1) that explains 54% of the overall heterogeneity. A potential second factor has been omitted as it would have explained only a small proportion of variability. The factor loadings give the greatest weight to design (0.79), with slightly lower weights to sourcing new business processes (0.62) and R&D (0.60) with software and new equipment (0.48) and branding and marketing (0.43) carrying the lowest weights. Notice that the factor includes both technological (tangible) and managerial (intangible) elements reflecting that when firms source innovations, they tend to source managerial and technological innovations simultaneously.

Having just one principal factor allows a simple calculation for each firm of an aggregated summary measure of overall sourcing, the factor score. In Figure 1 we present the distribution of the standardised scores across the firms in the sample, illustrating a wide, heterogeneous, spectrum with the most populous values being in the three classes corresponding to the lowest intensity of sourcing. The majority of the firms report values of overall sourcing below average with the median (-0.87) and the trimmed mean (-0.47) less than the arithmetic mean.

Figure 1. Distribution of the intensity of the sourcing of innovations (standardised factor score) across the sample firms.



Decomposing the scores of the firms in the sample, using the criteria of distance minimization, we undertake a two-step cluster analysis and identify three clusters of firms (A, B and C) within which firms share similar patterns of intensity of sourcing. Battisti & Stoneman (2010) find a very similar pattern of three clusters but their data relates primarily to the use and not the sourcing of innovations. Table 4 presents the numbers of firms in each cluster and the mean standardised factor score for the cluster. The first sourcing cluster, labelled A, contains 44% of the sample. These firms have a level of engagement in sourcing innovations that is low (average score = -0.922) and below the overall average standardised score (zero). Cluster B contains firms that engage only moderately in sourcing innovations (average score = 0.36), while cluster C (15% of the sample) contains those that engage most in sourcing with an intensity (1.67) almost 6 times higher than that for firms in cluster B. These results indicate that investments in sourcing both technological and managerial

innovations (or tangible and intangible capital) is very concentrated in a small number of firms (a result echoing the results of Riley & Bondibene, 2018)).

Table 4. Average intensity of sourcing innovations: average intra-cluster (standardized) score and sample sizes.

		Sourcing of innovations (Standardized factor score)		Sample sizes	
		Mean	Std. Dev.	N	%
Cluster	A	-0.92	0.32	625	44.4%
	B	0.36	0.37	562	39.9%
	C	1.67	0.33	220	15.6%
	Total	0.00	1.00	1407	100.0%

Table 5 shows the within-cluster percentages of firms who report having been active in sourcing particular types of innovation. R&D is least seen, while 'branding and marketing' along with 'software and new equipment' are the most seen. No special pattern is detected when the clusters are observed across the range of types. The intensity of engagement in all activities steadily increases from cluster A to C, suggesting that the firms that are most active in sourcing innovations of one type are also the most active sourcing other types. In particular one sees that firms that engage most in sourcing one type of innovation, say intangibles, also engage most in sourcing other types, say tangibles. These observation reinforce the view that

different types of innovations are complements rather than substitutes. For brevity we label firms in cluster A as least innovative, and those in cluster C as most innovative.

Table 5. Percentage of sample firms sourcing innovation by activity and cluster.

Cluster	Sample size	R&D	Design	Change to business processes	New equipment and software	Branding and marketing
A	625	3	5	6	21	24
B	562	23	42	43	69	67
C	220	68	92	90	90	90

Analysis of the distribution of firms across the three sourcing clusters provides support for the hypothesis that the levels of sourcing of innovations by firms will differ across firm and industry characteristics. We discuss firm characteristics in the Appendix. Across industries, reflecting perhaps technological characteristics of products and market structure, a large proportion of the firms in architecture and the software industries for example, are in the highly active cluster C whereas more than 50% of all firms in accountancy and construction are in the less active cluster A. However, the patterns for automotive, construction and energy production do not differ markedly from the other industries and we thus conclude that firms outside of the service sector are no more or less active in sourcing innovations than firms in that sector.

4.2 The use of innovations

Applying IPFA to the decomposition of the tetrachoric correlation matrix of the pair wise use decisions for the firms in the sample we have identified two factors (see Table 6 for the factor

loadings and their uniqueness statistics). The two factors account for about 90% of the overall heterogeneity in the adoption of innovations. The data indicates that the first factor (Factor 1), driven by the extent of use of strategy, management, organizational and marketing innovations (i.e., managerial innovations or intangibles), accounts for 79.5% of the total variability in firms' overall innovative activity. The second factor (Factor 2) in Table 6 explains 10% of the remaining variability in the heterogeneity of the use of using innovations and is driven by technological innovations i.e., the introduction of new products or services and new business processes (tangibles). This analysis suggests that managerial innovations play a predominant role in our sample of UK firms. These factor compositions are in line with the findings of Battisti & Stoneman (2010) using data from the UK Community Innovation Survey.

Table 6. The use of innovations: rotated factor loadings and unique variances

Innovation Type	Factor 1 managerial	Factor 2 technological	Uniqueness
New product/service	0.2368	0.6375	0.3706
New process	0.3404	0.6975	0.3220
New strategy	0.7975	0.2744	0.1869
New management technique	0.4100	0.2440	0.4432
New organisation structure	0.7475	0.2493	0.2826
New marketing	0.4661	0.2094	0.2821
% Variance	79.52	10.03	

A two-step cluster analysis based on distance minimization of the projection of the firms standardized factor scores identifies 4 clusters of firms (the Kaiser-Meyer-Olkin measure of overall sampling adequacy is 0.8652) based upon the intensity of use of the 6 types of innovations. We label these use clusters from 1 – 4 (in contrast to the sourcing clusters labelled A, B and C above). Cluster 1 has a high level of use of managerial innovations and a low level of use of technological innovations, cluster 2 has low levels of use of both, cluster 3 has low levels of use of managerial innovations and a high level of use of technological innovations, whereas cluster 4 has a high level of use of both. Only 13.9% of the firms in the sample report intensive use of all types of innovations (are in cluster 4) whereas 57.5% of firms score low in the adoption of both technological and managerial innovations (are in cluster 2). Overall (see Table 7) about 30% of the firms score highly in the introduction of new products and processes (13.9% in cluster 4 + 15.7% in cluster 3), whereas about 27% have scored highly in the introduction of managerial innovations (12.8% in cluster 1 + 13.9% in cluster 4). The concentration of managerial innovation in a limited number of firms again reflects the findings of Riley & Bondibene (2018) that investments in intangible capital are concentrated in a small number of firms.

Table 7. Average standardised factor scores and distribution of firms across use clusters

		Average Z-Score		Sample size	
		Factor 1 managerial	Factor 2 technological	N	% of Total
Cluster	1	1.6713	-0.7956	185	12.8%
	2	-0.5012	-0.4944	829	57.5%
	3	-0.6660	1.4577	227	15.7%
	4	1.2807	1.1247	201	13.9%
	Total	0.0000	0.0000	1442	100.0%

The data indicates that firms in cluster 4 extensively use both managerial and technological innovations. Firms in cluster 2 use both only to a limited degree. This would be consistent with managerial and technological innovations being complements. However, firms in clusters 1 and 3 illustrate extensive use of one type and lesser use of the other type of innovations. For these firms therefore, although we have shown that there are some complementarities across the different innovation types, those complementarities may not extend to encompass the full package of activities labelled managerial and technological innovations. In fact, for these clusters managerial and technological innovations may instead be substitutes, or at least not complements. This differs from our findings when we looked at the sourcing (rather than using) of innovations where there was a strong suggestion of complementarities across all innovation types. It also contrasts with the patterns of use identified in Battisti and Stoneman (2010), who find that only three clusters of firms can be identified, across which the intensity of use of both sets of innovation are positively linked and scores are either: below average (56.9% of the sample); intermediate but above average (23.7%); or highly above average (19.4%).

Analysis of the distribution of firms across the four using clusters provides support for the hypothesis that the extent of using of innovations by firms will differ across firm and industry characteristics**.** Differences across firm characteristics are discussed in the Appendix. As regards differences across industries, in all industries the majority of the firms are in cluster 2 (where use of both managerial and technological innovations is low). The industries with the highest percentage of firms in this cluster are accountancy, 71.5%, construction, 68.2% and legal services, 63.8%). Although there are one or two obvious outliers, in general the pattern suggests that service and manufacturing industries differ little from each other in terms of

their total innovativeness as measured by the use of innovations, although the types of innovation that they undertake differ.

4.3 Synergies between sourcing and using new innovations

To empirically explore synergies between the sourcing and use of innovations we first investigated the use patterns of firms across source clusters A, B and C. The data show, as one would expect, that there is a strong association between the intensity of effort in sourcing of innovations and the actual adoption or use of innovations. For all the different types of innovation, the proportion of using firms is highest in cluster C and lowest in cluster A with the adoption of innovations being 3 to 4 times higher in cluster C than in cluster A i.e., firms that invest most intensively in sourcing of innovations (cluster C) are also the most active in adopting innovations.

Secondly, we compared the intensity of sourcing of innovations by the firms in the four different use clusters. The data in Table 8 shows that there is considerable heterogeneity in each cluster with sourcing activity by innovation type differing within usage clusters and also usage activity differing by sourcing activity by type. Cluster 2, the lesser using cluster has the lowest scores for all source types while cluster 4, the cluster with most use, has the highest (except for changes to business processes) for all source types. Clusters 1 and 3 are similar except for the very high score for cluster 3 re the sourcing of new business processes. The last row shows that: cluster 4 has the highest overall average score, cluster 2 the least. Cluster 3 outscores cluster 1 suggesting that firms using mainly technological innovations source innovations more intensively than firms mainly using managerial innovations.

These data suggest positive correlations between the intensity of sourcing and using innovations. To more formally explore the degree of association between the two stages of the innovation process we cross-tabulate the four use clusters and the three sourcing clusters (Table 9). Applying a Chi-square test (χ^2=542.229; p=0.000) to this data confirms that, overall, there is a significant positive association between the propensities to source and use innovations. This suggests positive complementarities between sourcing and use.

Table 8: Sourcing of innovations by use clusters: intra cluster average (percentage of firms)

Innovation sourced by type	Use clusters				
	1 (use mainly managerial innovations)	2 (use low levels of both types of innovations)	3 (use mainly technological innovations)	4 (use high levels of both types of innovations)	Total
R&D	25	12	27	47	21
Design	35	21	47	65	33
Changes to business process	17	4	100	95	34
New equipment and software	49	43	59	73	51
Branding and marketing	57	44	55	70	51
Total number of firms	178	789	216	191	1374
Factor score (average)	-0.06	-0.48	0.72	1.15	0.00

NB: list-wise deletion of missing values

Table 9: Cross-tabulation of sourcing (3 clusters) and use of innovations (4 clusters): number of firms (% of total)

	Sourcing clusters			
Use clusters	A (low)	B (moderate)	C (High)	Total
Cluster 1 (mainly using managerial innovations)	74 (5.4%)	91 (6.6%)	13 (0.9%)	178 (13.0%)
Cluster 2 (using low levels of both types of innovations)	508 (37.0%)	257 (18.7%)	24 (1.7%)	789 (57.4%)
Cluster 3 (mainly using technological innovations)	28 (2.0%)	120 (8.7%)	68 (4.9%)	216 (15.7%)
Cluster 4 (using high levels of both types of innovations)	8 (0.6%)	76 (5.5%)	107 (7.8%)	191 (13.9%)
Total	618 (45.0%)	544 (39.6%)	212 (15.4%)	1374 (100.0%)

5. INNOVATION AND CORPORATE PERFORMANCE

There is considerable literature (see above) that suggests that firm performance and innovative activity are positively correlated, although directions of causality are still an open issue. The data source offers only a limited choice of performance measures. Riley & Bondibene (2018) have been able to use productivity measures and show a close association between productivity performance and investments in intangible capital. Battisti and Stoneman (2019) have emphasised a profit- based measure. We do not have either productivity or profit measures available in the data set employed and thus, largely on the

grounds of sample size, for this is a measure upon which there is extensive data, we have chosen sales growth in the three years prior to the survey date as our firm performance indicator. In the data set this may take three values, increased, decreased or stayed the same. It is also a measure used by Bloom & Van Reenen (2007). About 57% of the firms in the sample registered an increase in their sales with the remaining firms split almost equally between those that report having decreased sales (23%) or sales staying the same (20%). We concentrate upon analysing differences in performance between firms in different sourcing and using clusters, rather than relating performance to individual sourcing or using activities, in line with arguments above that firms undertake different sourcing and using activities simultaneously. Extant studies also argue that the benefits derived from one innovation crucially depend on whether other innovations are already in place (see, for example, Ichniowski et al. 1997, Whittington et al. 1999, and Battisti & Iona, 2009, Black & Lynch 2004).

Analysis of the sales growth of firms by sourcing cluster indicates that that of the firms in (the innovative) cluster C, 71% experienced increased sales and 14% experienced decreased sales, whereas for firms in cluster A (the least innovative) the figures are 50% and 28% respectively. Alternatively, of firms that experienced sales growth, over 70% are in cluster C. Clearly there appears to be a positive relationship between sales growth and the intensity of sourcing. A chi-square test of association across clusters $\chi^2(4) = 30.642$ p=0.000, rejects the null hypothesis of no association.

Analysing the sales growth of firms across usage clusters, indicates that about 71% of firms in cluster 4 (high scores on both factors) report increased sales, compared to 58%, 53% and 57 % in clusters 1 (mainly managerial), 2 (low level of both) and 3 (mainly technological)

respectively. Only 17% of firms in cluster 4 report decreased sales compared to 21% in cluster 1, 19% in cluster 3 and 27% in cluster 2. These results suggest a positive link between sales growth and the adoption of a range of both technological (process and product) innovations and managerial innovations. A chi-square test of association by cluster, $\chi^2(6) = 23.314$ $p=0.001$, rejects the null hypothesis of no association.

The nature of these two sets of results relating to sourcing and use further indicates that firms experience complementarities in the innovation process, in that higher payoffs are enjoyed by firms that undertake joint adoption rather than adoption of any one type alone or no adoption at all. Specifically: a firm undertaking (sourcing or using) technological innovation experiences greater improvement in sales growth if it also undertakes managerial or organisational innovation); and (ii) a firm undertaking (sourcing or using) managerial innovation experiences a greater improvement in sales growth if it also undertakes technological innovation.

6. CONCLUSIONS AND IMPLICATIONS

Innovation activity has here been considered to encompass both managerial (or intangible) activities reflected in changes to management techniques, organisational strategy, organisational structure, and marketing methods, and technological (or tangible) activities encompassing new or significantly improved products (goods or services) and processes. The analysis reported here upon is mainly perceived as not only detailing the patterns and determinants of managerial and technological innovation but, more importantly, contributing to a small but growing literature that addresses the interaction between the two.

The paper extends previous CIS based work by the same authors using an existing data set that relates to innovation in a sample of 1497 UK enterprises in 2009 with a deliberate bias towards the service sector (about innovation in which relatively less is known). The data represents innovation as a three-stage process encompassing sourcing (involving five different sub activities encompassing both the managerial and technological), using (involving six different sub activities also encompassing both the managerial and technological), and exploitation (measured by changes in firm performance).

Between one fifth and one half of all firms in the sample have engaged in each of the different sourcing activities. However, the pattern of sourcing across innovation types differs considerably across industries. On average just above a third of the sample firms (36%) have actively engaged in the introduction of at least one of the innovation types identified. However, the pattern of innovation types introduced differs considerably across industries. The data clearly indicates that no one type of innovation is more or less prevalent than any other overall in sourcing and introduction, and as such, consideration of the full range of innovation activities is an important aspect of judging and measuring the innovativeness of industries and firms.

It is also observed that firms simultaneously source and simultaneously introduce different types of innovations, both managerial and technological. We find evidence to support the hypothesis that there is considerable complementarity in the sourcing and use of different innovation types. In the presence of simultaneous sourcing and use of different innovation types, any single measure of sourcing or usage by a firm requires a set of weights to apply to each individual innovative activity in the summing over such activities. Iterated Principal Factor Analysis was used for this purpose.

For sourcing, a single principal factor was identified that allocated (different) weights to undertaking design activity, R&D, sourcing software and new equipment, and branding and marketing, i.e., both technological and managerial innovations. The estimated values of this factor across the sample firms, measuring the overall innovation sourcing activities of the sample firms, yielded three clusters. Cluster A (44% of the sample) contains firms that have a level of engagement in sourcing innovations that is well below the overall average. Cluster B (41%) contains firms that engage only moderately in sourcing innovations although considerably more extensively than firms in cluster A (especially as regards R&D or design). Cluster C firms (15% of the sample) engage most in sourcing with an intensity almost 6 times higher than that for firms in cluster B. Noticeably the extent of engagement with sourcing simultaneously increases for all types of innovation as one moves from cluster A through C. For example, firms in cluster C are not only doing more sourcing of managerial but also more sourcing of technological innovations.

Following similar procedures, from the sample data on the use of innovations two principle factors are identified (one relating to the use of what are labelled managerial innovations and other to the use of what are labelled technological innovations) enabling the identification of four clusters of firms. Cluster 1 (13% of the sample) has a high level of use of managerial innovations but a low level of use of technological innovations; cluster 3 (16%) has low levels of use of managerial innovations but a high level of use of technological innovations; cluster 2 (57% of the sample) has a low level of use of both technological and managerial innovations; cluster 4 (14% of the sample) has a high level of use of both technological and managerial innovations. Further analysis of the data shows that there is a strong association

between the intensity of sourcing innovations and the actual adoption or use of innovations. Firms most active in one stage are also most active in the other.

Analysis of the distribution of the factor scores of firms across the three sourcing clusters indicates that there are differences across industries but service sector firms are no more or less active in sourcing innovations than firms in other sectors. Similarly, in general, the factor scores suggest that service industries differ little from others in using innovations although the types of innovation that they undertake may differ. Analysis of the distribution of firms across the three sourcing clusters and the four use clusters in an appendix provides support for various hypotheses that relate firm characteristics to innovativeness largely as the existing literature would suggest.

Measuring performance by the sales growth of firms we find a clear positive association of such growth with the intensity of sourcing innovations. We also find a positive relationship between sales growth and the use of innovations, both technological and managerial, with better performance associated with extensive joint use and lesser performance associated with adoption of either managerial or technological innovations alone or no adoption at all. This reinforces the view that at least some firms experience complementarities and obtain higher payoffs from joint sourcing and/or simultaneous adoption of different innovation types.

In sum there are types of innovation that we may label managerial or organisational, beyond the technological, that have tended to be relatively ignored in the literature. The impact of managerial innovation upon firm performance may be studied in isolation (as may the impact of technological innovation), but as different innovation activities are often undertaken simultaneously, all must be jointly considered in any analysis of the contribution of

innovation to improvements in firm performance. This would suggest that studies of the impact of innovation on firm performance that look at technological or managerial innovations alone may well attribute to one type of innovation improvements in performance that that are in reality attributable to the other type, or at least to both types jointly. Studies of the impact of innovation upon firm performance should encompass the several different types of innovation that firms undertake simultaneously, and, such studies should also take into account complementarities between such innovations.

Although there are innovative firms in all industrial sectors, the data here shows that the proportion of UK firms that are "very" innovative is small. Thus, in order to improve the average innovative performance of UK firms there may be a need for policy intervention. Our analysis cannot clearly indicate suitable policy instruments but it does suggest that policy should not be directed solely at production industries for other, service, industries are just as capable of being innovative. Nor should policy be directed at just technological innovation. There are other, managerial, innovation activities that may be as or more relevant to both the service and production sectors and thus may be at least as necessary or better to target. In addition, the existence of complementarities across innovation types and stages indicates the desirability of policies with a wide rather than a narrow stance and which thus encompass (i) all types of innovations and (ii) sourcing, use and exploitation.

APPENDIX: INNOVATION AND FIRM CHARACTERISTICS

A.1 Hypotheses

Without implying causality, we hypothesise, largely upon the basis of existing literature, that the main firm characteristics to which both the extent and perhaps the structure of the sourcing and use of innovations will be related are as follows.

(i) Firm size, which picks up a number of firm characteristics such as efficiency and management abilities (Astebro, 1995), resource capability and displays of greater innovative competence (Mansfield 1968, Hannan & MacDowell, 1984). Although the impact is not obvious (Noteboom, 1993 & Damanpour 2010), large firms are often found to be more innovative.

(ii) Home or foreign ownership[13], as it is often found that plants owned by non-UK domiciled transnationals are more efficient and/or more productive (Griffith et al 2004, Bloom & Van Reenen, 2007).

(iii) Whether the firm offers both services and physical products rather than either alone, perhaps with cross reference to the servitisation argument (Vandermerwe & Rada 1988, Neely, 2008, and Baines et al. 2009). A positive impact on innovation is expected.

(iv) The proportion of employees with a degree, which will reflect workforce skills, and a positive impact on the extent of innovation is expected (Bartel & Lichtenberg, 1987, Caroli & Van Reenen, 2001 and Bresnahan et. al. 2002).

(v) The percentage of turnover from exports, it being considered that exporting firms reveal themselves as more innovative and efficient (Harrison, 1996, Wakelin, K. 1998, Cassiman et al 2010) and thus a positive impact on the extent of innovation is expected.

[13] Unfortunately, we do not have data that would enable us to separate out family-owned firms as do Bloom and Van Reenen (2010).

(vi) The level of product uniqueness, which is an indicator of competitive pressure, with the literature being agnostic to whether it will have a positive or negative impact (see among others, Vives, 2008, Geroski 1990).

(vii) Whether the firm is independent or part of a group, reflecting the positive impact of internally sourced information and competencies and different degrees of autonomy (see for example Cainarca et al. 1990 and Dunne, 1994).

(viii) The age of the business surveyed, because older firms may have accumulated knowledge that allows them to assess innovations better than younger firms (Noteboom 1993), although the opposite might also be true (Little & Triest 1996).

A.2 Empirical results: firm characteristics and the extent of sourcing

Analysis of the distribution of firms across the three sourcing clusters provides support for hypotheses that relate the levels of sourcing of innovations to firm characteristics. Looking at the characteristics of firms in the three different sourcing clusters we found that, although there are no significant differences with respect to the age of the business, a firm is more likely to be a member of the high sourcing cluster C, if it is larger, foreign owned, offers both physical products and services, has a proportion of employees with a degree between 11 and 20%, has a higher percentage of turnover from exports and some product uniqueness. On the other hand, a firm is more likely to be found in the lesser sourcing cluster A if it is UK owned, offers only products or services alone, has less than 5% of employees with a degree and does not export.

A.3 Empirical results: firm characteristics and the extent of using innovations

Analysis of the distribution of firms across the four using clusters indicates that, compared to the average, firms in cluster 2 (the least innovative) are more likely to be service only firms and have lower exports. On the other hand, firms in cluster 4 (the most innovative) relative to other firms are more likely to: sell both physical products and services (in line with the theory of servitisation see Neely, 2010); be export orientated; are either totally or partially foreign owned; are part of a group. We have also found that firms in cluster 4 tend to be larger, have the highest share of firms (91%) with more than 5% of employees with a degree (whereas cluster 2 has the largest share of firms (22%) with less than 5% of employees with a degree). Cluster 1 firms (who have a high level of use of managerial innovations but a low level of use of technological innovations) are slightly larger than cluster 3 firms (who have low levels of use of managerial innovations but high level of use of technological innovations) have about half the number of employees on average of cluster 4 firms. These findings in general support the hypotheses above. This should be no surprise given that we have also shown that the sourcing of innovations is similarly related and that there is a significant positive association between the propensities to source and use innovations.

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