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Open by Design:
The Role of Design in Open Innovation

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THE ROLE OF DESIGN IN OPEN INNOVATION

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Executive Summary

In this study, we have two linked objectives: (1) to capture a better understanding of what we mean by "open" styles of innovation and how these can be defined, and (2) to test whether firms need design capabilities and a suitable sectoral fit to be open. This study is distinctive in terms of its method and its conceptualisation of design. We test our hypotheses through a large-scale cross-sectional data set of 16,445 firms from the UK Innovation Survey Database. Design, for this research, reflects an instrumental rather than aesthetic goal for its role in negotiating the partitioning and interfaces in innovative tasks, suggested in the open innovation model.

"Open" styles of innovation are not new phenomena, either in practice or in the scholarly literature. However, the emphasis on "open innovation" reflects a greater awareness of the organisation of innovative and productive activities across firm boundaries and a more equal footing between internal and external sources. Many authors have explored some of the capabilities and outcomes of firms with an "open" strategy for innovation. However, "openness" has been measured differently and without sufficient review of how and why these measures correlate or not. The approach has been to treat open innovation as a general tendency with multidimensional forms of expression, when it may be (and other authors have suggested) an umbrella term for different organisational behaviours which have meaning in different contexts.

Open Innovation resonates with descriptions of innovation from another area of study, that of complex products and systems (CoPS). CoPS are high-value, software-intensive, customised capital goods, and their complex design and thin market characteristics generally require close co-operation between firms in the value chain and the customer. As such, firms producing and using CoPS have regularly demonstrated "open" practices of innovation to co-ordinate and collaborate on the innovation task, prompted by need (problem solving) or by opportunity (improved functionality).

Design not only makes task partitioning possible but, more generally, the range of innovative activities with external sources suggested by the open model of innovation. Just as absorptive capacity matters for technology transfer, design capacity matters to the practice of open innovation strategies because of the importance of interfaces in task partitioning. Specification of tasks and task interfaces is achieved by design – organisational design in the specification of tasks and technical design in the task interfaces. The question remains whether open innovation practices, and the design capacities supporting these, are now uniform across markets and sectors, or whether different sectors have evolved open innovation structures more readily than others. We explore in this paper not only whether "openness" has a coherence in modes of expression (search patterns, collaboration, IPR regimes), but also whether open innovation is generalisable across sectors.

We set out to test:

H1: 'Open' innovators need more developed design capabilities to manage innovation across organisational boundaries.

H2: Open patterns of innovation will vary by sector, reflecting differences in market conditions, opportunity (technological and organizational) and organizational structures for innovation.

For this research, we have employed a two-stage large scale, quantitative and cross-sectoral research design. Using the UK Innovation Survey Database 2005 of 16,445 respondents, in the first stage of the study we explore different measures of "openness", some of which have been used in previous open innovation studies and others which also

express open practices as described in the Open Innovation literature. In the second stage of the study, we then test for the importance of design and sector for our respondents defined by open innovation practices.

In the Open Innovation literature, the degree of "openness" of a firm in its innovation practices has been operationalised in different ways. Typically, researchers identify the firm's intent to more extensively use external sources of technology and knowledge. A lead practice for this intent is the practice of sourcing information (and potentially knowledge) from outside organisations, both in terms of breadth (range of sources) and depth (importance of sources). A second practice often studied is collaboration patterns by type and location of collaborator. Two further practices are possible to assess through the database: a direct measure of the external sourcing of knowledge and R&D and the authorship of a listed innovation. We look for the patterns of correlation and consistency across these measures to help define what we mean by "open".

We test the association between "openness", design practices and sectors. The UK Innovation Survey database holds data on design activities as well as measures of design as a means to protect innovation. We use all three of these measures in the analysis. Market uncertainty is recorded at the firm level through respondent assessments in the survey. To capture differences across sectors, we categorise respondents in two ways. First we test respondents that are classified CoPS producers and CoPS-based services in accordance with previous research (Acha et al, 2004). We then group and test respondents using the seven broad industrial classifications used by the Department of Trade and Industry in its innovation analysis. Size of firm, share of qualified scientists and engineers in the workforce and internal R&D are used as controls in the models.

We find relatively low correlation and consistency (as measured by Cronbach's alpha) between the different measures of "openness". Except where questions are linked, the relatively low correlations suggest that each metric is capturing a different group of firms exhibiting different open innovation styles. This has important implications at a theoretical and an operational level. At the theoretical level, the implications are that there are many facets of openness and we could anticipate the development of a typology of open innovation styles for firms and potentially sectors. At an empirical level, the choice of "open" innovation measure will result in different statistical outcomes. For this study, we focus on the markets for technology measure (external acquisition of R&D and knowledge) as this has the most immediate link to open innovation practice, but we test the robustness of results against the models for information sourcing (breadth and depth).

We find support for our hypotheses that open innovators need more developed design capabilities and that open patterns of innovation vary by sector and market conditions. We also find interesting differences between open innovation measures, with greater consistency between firms that acquire knowledge and R&D externally and firms that source information broadly, and less so with firms that attach greater importance to their external sources of information. For example, we find that greater demand uncertainty for innovative goods and services makes depth less likely. Where market uncertainty is present, we can suggest from this finding that the firm's response is to look widely, rather than deeply. Amongst the sectors, CoPS-based services and knowledge-based services demonstrate the greatest association with open patterns of innovation.

As the analysis of measures demonstrates, "open" is an umbrella term for the various means, depths and motives for reaching across organisational boundaries to achieve an innovation task. Design provides the translation of understanding and expectation between organisations engaged in open innovation practices. The findings demonstrate that firms which actively undertake design activities for innovation and which use design to control the innovation process, are more likely to also pursue open strategies for innovation, although

these strategies may include different practices. Our findings are robust in scale, but not in kind to the use of different measures for open innovation practices and we elaborate emergent typologies suggested in the sectoral variation. Knowledge-intensive services (which would include CoPS-based services as well) stand out in our analysis as leading sectors for open innovation practices. This is a new insight for the open innovation discussion, as very little analysis has been done on open innovation practices in the services. Overall, this research suggests that we can refine our understanding by exploring the nature of the innovative task, the drivers and potential for its partitioning, and how these dynamics are conditioned by the wider industrial environment.

This study has highlighted the role of design capacity as a core capability for open innovation practice, and as such, managers and policy makers should pay greater attention to the role of design capacity in extramural, open innovation, achieved either through collaboration or through contract. Moreover, this research presents further evidence that our understanding of the role and nature of design is still woefully lacking, in comparison to the substantial work completed on defining and characterising R&D, science, technology and even innovation itself. Moreover, this study suggests that openness as an innovative strategy is not a panacea nor a simple choice, for the firm or the policy maker.

In the Open Innovation literature (Chesbrough, 2003a, Chesbrough et al., 2006), the decision to be "open" is a choice for firms to make in line with their business models, and this choice is revealed in their external search patterns (Laursen and Salter, 2006) and judged in terms of their innovative and economic outcomes. In this paper we pursue what it means to be "open" and what conditions this choice. Using the UK Innovation Survey Database 2005, we test different measures of "openness" across a large data set and find that open innovation practices vary across firms and sectors, giving support to the view that openness is not strictly a choice for the firm but an outcome of capabilities, industrial organisation and wider innovation systems. Within the firm, design is revealed as a core capability that shapes open innovation practice, reflecting its role in innovation task partitioning. We confirm this in our robust findings that design is accorded higher importance by firms which have open innovation practices.

1 Introduction

The model of Open Innovation (Chesbrough, 2004, Chesbrough, 2003a, Chesbrough and Crowther, 2006, Chesbrough, 2007, Chesbrough, 2003b) has found a ready audience amongst business leaders and policy makers who recognise that external sources of technology and knowledge are playing a more pronounced role in innovation. This model supersedes the old "closed" model of innovation, which Chesbrough argues played its role in the 20th Century. Whereas the "closed" model of innovation is centred on the firm's internal R&D and innovative practices to provide competitive advantage, the open model includes both internal and external R&D, technologies and innovations in the firm's potential portfolio, as well as both in-bound and out-bound trajectories for these innovations. The firm should choose whatever options and routes provide the best fit with their business model.

Of course, the organisational structures and practices that each model would require are very different. The closed model has to balance tensions between R&D departments and the profit centres. Chesbrough et al (2006) describe a "valley of death" for some innovations, that occur when ideas stall somewhere between proof of concept (or prototype) and take-up by a production department or a business unit. The innovation literature is well stocked with scholarly contributions on the comparative value of different sizes, compositions and incentive structures for R&D units. Equally challenging has been the drive to determine what to invest in and with what time horizons, and what key performance indicators to use to mark the way. Scholars have accomplished a great deal to better understand how firms marshal resources for innovation from within the firm. However, with some very notable exceptions (Cohen and Levinthal, 1990, Cohen and Levinthal, 1989), the contributions to help us to understand how firms marshal innovation externally have been more recent. We can track this change in focus from within the firm to outside the firm, in the evolving conceptualisation of 3rd Generation R&D, 4th Generation R&D ((Miller and Morris, 1999), 5th Generation R&D (Rogers, 1997). and 6th Generation R&D (Nobelius, 2004), not forgetting Rothwell's (1994) extension, "Towards the fifth-generation innovation process".

Greater attention remains with external linkages for innovation, perhaps in response to the Open Innovation literature and very likely due also to the wider changes in global production and markets that have emphasised the importance of networks and value chains. Scholars have explored what capabilities firms need to master to engage in "open" styles of innovation (Laursen and Salter, 2006, Christensen et al., 2005, Dodgson et al., 2006, von Hippel and von Krogh, 2003, Wagner, 1991). Indeed this literature has resonated with descriptions of innovation from another area of study, that of complex products and systems. Complex products and systems (CoPS) (Hobday, 1998, Hobday and Rush, 1999, Hobday et al., 2000, Acha et al., 2004, Davies and Brady, 2000) are high-value, software-intensive, customised capital goods. Because of the customisation and complexity in the design of CoPS, these products are produced by a network of firms who have to co-ordinate and partition the innovation task, which is then integrated by a lead firm. These processes of task partitioning and integration are dependent upon design activities. Because the markets for CoPS are thin and sales come along as events and not as streams, the CoPS producer negotiates design directly with the customer as well as potential users to minimise technical and market uncertainty. The result is a pattern of innovation that is necessarily "open". However, the importance of this example is not that open innovation is in evidence, but that open

innovation is shaped by firm capabilities (specifically design capabilities), industrial organisation and the wider innovation systems of CoPS producers.

In this paper, we explore what it means to be "open", bearing in mind the need suggested by other authors to more exactly define what open innovation comprises (Helfat and Quinn, 2006, Gann, 2005, Dahlander and Gann, 2007). We develop and test several measures, and explore how these vary across firms and sectors. Using a selection of these measures, we then associate "openness" with the firm-level capabilities of design suggested by the CoPS research as well as sectoral and market variables. We find that the concept of open innovation masks a variety of practices that vary by firm and sector, which we argue reflects the different drivers and opportunities of firm capabilities, industrial organisation and innovation systems beyond the strategic choice to be open. This research contributes further to the argument that open innovation practice is conditioned and perhaps bounded by factors outside of the firm (Christensen et al., 2005). However, across all measures of openness tested, we find that design emerges as a core capability of an open innovator. There has been comparatively less research to date on the role of design in the innovation process generally with some notable exceptions (Marsili and Salter, 2006, Tether, 2006, Whyte et al., 2005, Rothwell and Gardiner, 1983, Walsh et al., 1992). The focus of these studies, however, has been on the role of design as an input to the innovation (product or process) rather than the role of design in the conduct of innovative activity. This contribution is unique in linking design specifically to the role of collaborative and externally sourced innovation, or more generally stated open innovation. We structure the paper as follows. In the next section, we situate this research within the wider work on open innovation and complex products and systems in order to build our two hypotheses. We present the methodology in section three with special attention to the development of operational constructs for openness. The findings from the econometric analysis are presented in section four, and these are discussed and related to our theoretical frame in section five. We conclude with recommendations for policy and areas for future study.

In this study, we have two linked objectives: (1) to capture a better understanding of what we mean by 'open' styles of innovation and how these can be defined, and (2) to test whether firms need design capabilities and a suitable sectoral fit to be open. This study is distinctive in terms of its method and its conceptualisation of design. We test our hypotheses through a large-scale cross-sectional data set of 16,445 firms from the UK Innovation Survey Database. Design, for this research, reflects an instrumental rather than aesthetic goal for its role in negotiating the partitioning and interfaces in innovative tasks, suggested in the open innovation model.

2 Open Innovation in context

The Open Innovation literature is certainly not the first set of contributions to recognise the importance of external sources of technology and knowledge. The role of external sources of innovation has been explored from the first works on innovation and technology, through their potential to inspire (imitation), contribute (absorption of innovative inputs) and disrupt (radical innovation) the firms. Others have noted the long pedigree of notable authors who have explored the role of external sources of technology and knowledge, such as Schumpeter, Freeman, Cohen and Levinthal, Rosenberg 1994, von Hippel (1988), Granstrand et al 1997, Pavitt (1998); Langlois 2003. Indeed, the roots of the Open Innovation model overlap with these contributions.

Wagner (1991), for example, describes a model to foster and market innovation which involves "the open corporation" model inspired by his firm, Teknekron. He outlines a process of organisational structural flexibility of a satellite-hub model where new developments are formed as affiliate ventures. Chesbrough et al (2006) argue that what sets apart the Open Innovation model is that the open model places external sources on an equal footing with internal sources. External sources are now given the potential to alternate with the innovative opportunities within the firm.

2.1 What it takes to be "open"

Building on the research on external sources of technology and knowledge, recent papers have pursued the capabilities and structures that seem tobe associated with firms following an "open" strategy for innovation. Laursen and Salter (2006)[2] have focused on the open innovation practice of external search which they examine in terms of their innovative and economic outcomes at the firm level. Laursen and Salter also explore appropriability regimes (2005) to test for the "paradox of openness" as a curvilinear (inverted U) relationship between appropriation strategies and open innovation patterns amongst UK manufacturing firms. Leiponen and Helfat (2005) found evidence of the benefits of keeping options open, given the inherent uncertainty involved in innovation. Using the Finnish Community Innovation Survey (1997)[3], they find positive implications for success in innovation through following a "parallel-path strategy in innovation", where firms maintain an open strategy of sourcing information (breadth in sources) together with an "open mind" about the paths for innovation (breadth of objectives). Across these studies and others, the operational practice of "openness" is nuanced and different measures are deployed (sources of information, patterns of collaboration, IPR regimes) without sufficient review of how and why these measures correlate or not. The approach has been to treat open innovation as a general tendency with multidimensional forms of expression, when it may be (and other authors have suggested) an umbrella term for different organisational behaviours which have meaning in different contexts. We set out in this paper to begin this direct testing of the concept in this sense.

Indeed, these contributions have brought a greater understanding of what firms need to do to be "open", the implication being (as with much of the Open Innovation literature) that the decision to be "open" is a choice for firms to make. However, we will argue in this paper that some of the factors which make that choice possible are, to some extent, outside of the firm and indeed shape the firm's relationships with other organisations. This view has been less explored by other authors. One such contribution has been made by Christensen and colleagues (2005). They situate the concept of open innovation within a combined sectoral systems of innovation (Carlsson and Jacobsson, 1994, Edquist, 1997, Breschi et al., 2000, Malerba and Orsenigo, 1996, Malerba, 2002, McKelvey et al., 2003) and industrial dynamics approach to consider the contingencies under which a given firm will follow a particular innovation strategy: open, closed and often somewhere in between. They posit that the contingencies are framed by the firm's position in the innovation system, the nature and stage of the technological regime and the firms' choice of business model (Christensen

[2] Their work builds upon previous contributions on search strategies in new product development by Katila and Ahuja (2002) and the quality of knowledge under search by Katila (2002).

[3] The Finnish CIS is rather unique in collecting responses on 10 different innovation objectives as well as 12 different knowledge sources.

et al., 2005). Through a rich case study of the sound amplification industry at the point of a radical switch of technology, they conclude that firms will undertake different innovation strategies depending upon where they are in the sectoral innovation system and the extant technological regime (Christensen et al., 2005), implying persistent variance in the nature, composition and pay-off of being "open".

'Open' styles of innovation are not new phenomena, either in practice or in the scholarly literature. However, the emphasis on 'open innovation' reflects a greater awareness of the organisation of innovative and productive activities across firm boundaries and a more equal footing between internal and external sources. Many authors have explored some of the capabilities and outcomes of firms with an 'open' strategy for innovation. However, 'openness' has been measured differently and without sufficient review of how and why these measures correlate or not. The approach has been to treat open innovation as a general tendency with multidimensional forms of expression, when it may be (and other authors have suggested) an umbrella term for different organisational behaviours which have meaning in different contexts.

2.2 Open innovation in CoPS

We are building on the Open Innovation literature, but taking a different point of inspiration - 10 years of research on complex products and systems (CoPS)[4]. We consider CoPS here because this research has recorded patterns of innovation amongst CoPS-based firms which fit the descriptive profile of the open innovator. Examples of CoPS include aircraft engines, trains, bridges, gas turbines, offshore platforms, air traffic control systems, telecommunication systems and flight simulators. The markets for CoPS are generally thin, with relatively few sellers and buyers. CoPS are relatively novel in design because of the high degree of customisation of the product, which involves an iterative process of design and adjustment with suppliers and customers sometimes even after purchase.

In order to mitigate the technological and market uncertainty of introducing an innovation, firms that produce CoPS and services based on CoPS invest substantial time and resources to co-ordinating design and production across the value chain, customers, users and regulators. This collective organisation of innovation has resulted in the emergence of systems integration (Prencipe et al., 2003, Hobday et al., 2005) and integrated solutions (Davies and Brady, 2001) to deal with the challenges and opportunities of innovating with suppliers and users. As such, the increasingly complex and distributed (or networked) pattern of commercial innovation described in the recent literature (Chesbrough, 2003a, von Hippel and von Krogh, 2003, Coombs et al., 2001, Coombs et al., 2003), is nothing new for CoPS-based firms. The market and organisational logics which underpin the vertical scope of the CoPS-based value chains reflect the differentiated capabilities of the contributing firms and the co-evolution of these capabilities with transaction costs (Jacobides and Winter, 2005, Jacobides and Hitt, 2005).

[4] For over a decade, empirical study of CoPS was undertaken at SPRU (University of Sussex) and CENTRIM (University of Brighton) under the ESRC Centre for Complex Products and Systems. This wide-ranging programme of study advanced our understanding of the characteristics and dynamics of high technology, high value capital goods, which form the technological backbone of a modern economy. For further details, see www.cops.ac.uk.

The question is, what can we learn from CoPS that will better inform our understanding of factors that may enable an open innovation strategy? Because of the challenges of constant problem-solving, negotiated innovation and high interdependencies which require strong integration of the system, CoPS firms have devoted significant resources to design as an interface between the elements of production and additionally with the elements of the system for use. These interfaces facilitate integration at the system level, managing interdependencies across production across specialised firms in the CoPS value chain, to use the analytical framework of Jacobides and Winter (2005). Given the scale and complexity of CoPS in their design and production, these networks of suppliers are able to co-ordinate and collaborate on the regular occurrence of innovation prompted by need (problem solving) or by opportunity (improved functionality) because the innovation task has been *partitioned* effectively. Design is the means by which tasks are partitioned, and therefore design can be expected to play a role in open innovation structures.

Open Innovation resonates with descriptions of innovation from another area of study, that of complex products and systems (CoPS). CoPS are high-value, software-intensive, customised capital goods, and their complex design and thin market characteristics generally require close co-operation between firms in the value chain and the customer. As such, firms producing and using CoPS have regularly demonstrated 'open' practices of innovation to co-ordinate and collaborate on the innovation task, prompted by need (problem solving) or by opportunity (improved functionality).

2.3 Design in task partitioning and open innovation

Design has not had the attention in the innovation literature given to other practices (Tether, DTI Presentation, 2006), but its importance has been underscored in recent research (Whyte et al., 2005, Tether, 2006). Using the most recent UK Innovation Survey of 2005, Tether (2006) has demonstrated that design is an important complementary asset for innovation, particular for high level innovation. He also argues that design activities cross the boundaries between categories of R&D with contributions at all stages and throughout the innovation process, as suggested by von Hippel (1990). Recalling Simon's (1996) observation that engineers solve complex problems by decomposing them, Dodgson, Gann and Salter (2005: 111) argue that decomposing tasks allows teams to increase both the efficiency and the effectiveness of problem-solving. This decomposition falls within the "practice of design" (Dodgson et al., 2005: 110). We can extend this further to say that design not only makes task partitioning possible but, more generally, the range of innovative activities with external sources suggested by the open model of innovation.

Open innovation requires organizations to interact on an innovation task, and the ability to do this relies upon the design efforts of the organisations. Just as absorptive capacity (Cohen and Levinthal, 1990, Cohen and Levinthal, 1989) matters for technology transfer (and most likely for design), design capacity matters to the practice of open innovation strategies because of the importance of interfaces in task partitioning. Interfaces are visible design rules which detail how tasks and physical components are linked, how they will interact and the required points of communication (Baldwin and Clark, 1997, Langlois, 2002, Brusoni and Prencipe, 2006). Design interfaces make possible co-ordinated independence of task teams working together on a broader innovation task.

Von Hippel (1990) established the concept of task partitioning in innovation projects. "An innovation project of any magnitude is divided up ("partitioned") into a number of tasks and subtasks that may then be distributed among a number of individuals, and perhaps among a number of firms."(Von Hippel, 1990: 407) In this important article which anticipates not only the CoPS research but also the modularity literature, Von Hippel describes the modes by which task partitioning occurs and the efficiency gains that partitioning can generate when guided by the need and structural linkages for problem-solving across boundaries. Given that there are many ways to partition an innovation project, the challenge in task partitioning is to understand the interdependencies between tasks and how these can be better managed.

The design interfaces between tasks play a vital role in making the partitioning functional so that the innovation project is successfully completed. Von Hippel noted that at an extreme, "…if we were able to look at a completely partitioned project, what we would see is all component tasks and task interfaces specified, *implicitly or explicitly*, so that all would fit and work together to form the total project when combined."(ibid, emphasis added) Specification of tasks and task interfaces is achieved by design – organisational design in the specification of tasks and technical design in the task interfaces. In this sense, design is not a matter of aesthetics per se, but a means of translation and integration across tasks, stages of production and specialisations and even across to use.

We are addressing here this instrumental role of design capacity with respect to tasks, and in this sense, we follow many modularity scholars in recognising (and even linking) the role of design rules in organization (tasks) as well as in artefacts. Sanchez and Mahoney made the bold statement, "We suggest that although organizations ostensibly design products, it can also be argued that *products design organizations,* because the coordination tasks implicit in specific product designs largely determine the feasible organizations *designs* for developing and producing those products."(1996: 64) Brusoni and Prencipe (2006, Brusoni et al., 2001) have since argued from their work on the evolution of design rules in tires that *knowledge*, rather than products, designs organizations. We would add here that this knowledge critically includes design capacities for task partitioning and interfaces, and that this knowledge frequently goes beyond the demarcations suggested by the task partitioning itself.

This instrumental understanding of design draws on the important distinctions made by Vincenti in his categorical representation of engineering design knowledge, in which one of the key categories is "criteria and specifications" (Vincenti, 1990: 208). As Vincenti describes, "[w]ithout such technical specifications, the designer cannot start to contrive the details and dimensions that must ultimately be supplied to the builder. Assignment of the values or limits is usually (but not always; see below) particular to the particular designs and is best looked upon as part of the design process. The criteria themselves – the essential key to engineering specification – constitute an important element of general engineering knowledge. " (Vincenti, 1990: 211) The case studies for his analysis are drawn from the aeronautical industry, and Vincenti's purpose is to better define engineering knowledge and how it is developed. However, this instrumental role for design as a translator between stages of production or supply is equally valid where the relationship between organisations is in the collaboration or supply of intangibles, such as knowledge, R&D and intellectual property.

In a recent paper, Becker and Zirpoli (2007) explore a similar line of questioning on the task coordination across networks of firms in new product development in a very

complementary way. They argue, "[t]he key problem in managing innovation in networks ("open innovation") therefore consists in providing coordination of activities that are reciprocally interdependent." (Becker and Zirpoli, 2007: 2) Taking a case study on OEM manufacture, one of their findings is that the map for decomposing product architecture does not necessarily match that for coordinating across interdependencies, or that for decomposing innovation tasks. Clearly, design specifications along production lines (as Vincenti, 1990 describes) are not necessarily the regulator of innovative task partitioning (Von Hippel, 1990); we are describing instrumental design in a broader sense in the allocation of the innovative task(s) within and across organisations, and relates to knowledge which Becker and Zirpoli describe as "underlying component-specific knowledge" (2007: 31) and Vincenti describes as "the stored-up body of knowledge about how things are done in engineering" (1990).

H1: 'Open' innovators need more developed design capabilities to manage innovation across organisational boundaries.

This role of design in open innovation stands in contrast to a model of production where contracting firms deliver suppliers detailed specifications and drastically limit the contribution of the supplier to design and innovation; Langlois referred to this model as the nonmodular structure of production, which from the 1930s and the remainder of the 20th century dominated industry at least in the U.S. (Langlois, 2002: 33) "What distinguishes the new American collaboration *[in the automotive industry]*, like Japanese collaboration before it, is *increased modularity*. Rather than handing suppliers detailed instructions, manufacturers now give suppliers interface specifications and then encourage them to design the parts as they see fit." (Langlois, 2002: 34) The question remains whether open innovation practices, and the design capacities supporting these, are now uniform across markets and sectors, or whether different sectors have evolved open innovation structures more readily than others. The research by Christensen and his colleagues suggests that different innovation strategies are chosen depending upon where the firm is in the value chain. We take this logic further and suggest that different innovation strategies are also chosen depending upon the firm's market or sector. Factors such as uncertain demand for innovative goods and services may encourage the coordination of tasks through agreed interfaces in some sectors, as it happens in CoPS-based firms. In these circumstances open innovation practices and the role of design in these may be more apparent.[5] Not only, then, do we explore in this paper whether "openness" has a coherence in modes of expression (search patterns, collaboration, IPR regimes), but also whether open innovation is generalisable across sectors.

H2: Open patterns of innovation will vary by sector, reflecting differences in market conditions, opportunity (technological and organizational) and organizational structures for innovation.

[5] Podolny (1994) argues a very similar point. In his study of investment banking relationships, he found that market uncertainty prompted organizations to "…adopt a more social orientation, taking the social structural position of potential exchange partners as cues and adhering to a principle of exclusivity in selecting exchange partners"(p. 458).

Design not only makes task partitioning possible but, more generally, the range of innovative activities with external sources suggested by the open model of innovation. Just as absorptive capacity matters for technology transfer, design capacity matters to the practice of open innovation strategies because of the importance of interfaces in task partitioning. Specification of tasks and task interfaces is achieved by design – organisational design in the specification of tasks and technical design in the task interfaces. The question remains whether open innovation practices, and the design capacities supporting these, are now uniform across markets and sectors, or whether different sectors have evolved open innovation structures more readily than others. We test in this paper not only whether "openness" has a coherence in modes of expression (search patterns, collaboration, IPR regimes), but also whether open innovation is generalisable across sectors.

3 Method

To test these hypotheses, we use the UK Innovation Survey database 2005, which includes responses from 16,445 firms describing their innovation activities, investment and outcomes over the period 2002-2004. These responses were drawn from a sampling effort of over 28,000 UK enterprises with 10 or more employees. The survey was the fourth and most successful Community Innovation Survey conducted in the UK, with a response rate of 58% (Department of Trade and Industry, 2006: 56).[6]

The Innovation Survey is subject-oriented (Laursen and Salter, 2006), relying on firms to self-report their innovation outcomes (new products, services, processes), practices, barriers and collaborations. These innovation metrics are defined according to the Oslo Manual (OECD, 2005). Extensive pilot testing is undertaken by the UK Office of National Statistics to minimise the potential for response error. The UK is one of many countries in the European Union and worldwide to conduct an Innovation Survey based upon the core Eurostat Community Innovation Survey (CIS), and the main findings of the survey are aggregated for the European Union by Eurostat. These Innovation Surveys have provided the empirical basis for a growing body of literature.[7] In addition to information on innovation, the survey also captures data about the firm itself to provide the basis for deeper comparisons across types of firms and sectors.

For this research, we have employed a two-stage large scale, quantitative and cross-sectoral research design. Using the UK Innovation Survey Database 2005 of 16,445 respondents, in the first stage of the study we explore different measures of "openness", some of which have been used in previous open innovation studies and others which also express open practices as described in the Open Innovation literature. In the second stage of the study, we then test for the importance of design and sector for our respondents defined by open innovation practices.

3.1 Defining "Open"

This research is necessarily a two-stage process, where we first must undertake a

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[6] We gratefully acknowledge the provision of the database by the UK Department of Trade and Industry, which was organised under contract. Particular thanks go to Ray Lambert and Stephanie Robson of the Department of Trade and Industry, who co-ordinated this survey and research work.

[7] Laursen and Salter (2006) record more than 60 published academic articles using CIS data.

classification of survey respondents by open innovation practices. Despite the growth in the open innovation literature, there remain legitimate concerns about what exactly it means to be "open" in innovation (Helfat and Quinn, 2006, Dahlander and Gann, 2007). Several characteristic behaviours are presented by Chesbrough (2003a) and other subsequent authors. We would expect the firm to demonstrate relatively more acquisition of technology from external sources. We would expect the firm to demonstrate a more distributed pattern of innovation, with greater reliance on suppliers and customers in the process. We would expect the firm to trade their technologies relatively more in the market. We would expect the firm to rate external sources of knowledge and technology more highly. These expectations form a range of behaviours, and recent research (Christensen et al., 2005) suggests there is no singular profile for the open innovator.

In the Open Innovation literature, the degree of "openness" of a firm in its innovation practices has been operationalised in different ways. Typically, researchers identify the firm's intent to more extensively use external sources of technology and knowledge. A lead practice for this intent is the practice of sourcing information (and potentially knowledge) from outside organisations. In the UK Innovation Survey, this has involved a detailed analysis of Question 16, which asks "How important to your enterprise's innovation activities during the three-year period 2002-2004 were each of the following information sources?" (Department of Trade and Industry, 2005) and provides a list of eleven types of sources grouped as internal, market sources, institutional sources and other. In their work, Laursen and Salter (2006), develop this data into two metrics: *breadth* (the number of sources used and ranked of any importance) and *depth* (the number of sources used which were ranked by the firms as being of high importance). We create breadth and depth measures in the same manner, with the only difference being the number of sources indicated in the survey question. The earlier UK Innovation Survey used by Laursen and Salter listed 16 potential sources, whereas this Survey only lists 11.

Another practice indicative of "openness" is the firm's willingness to collaborate. This is operationalised as a direct question in the UK Innovation Survey (Question 17: "Did your enterprise co-operate on any of your innovation activities with other enterprises or institutes during the three-year period 2002-2004) with a yes or no answer. The survey then collects data on the different types of collaboration partners by their location, recording up to seven types including one within-group collaborator (Question 18). However, we do not have a sense of frequency or the extent of this recorded collaboration, and in this regard, the survey data can tell us only so much about the "openness" of a firm by this measure.

Less frequently used in the literature to date are two further measures of "openness": a measure of open innovation practices and the recorded "authorship" of innovations. The first of these is a question capturing the innovation activities and expenditures of the firm. Within this list (Question 13) are two categories of interest: (1) the acquisition of R&D (extramural R&D) which is defined as creative work purchased by the enterprise and performed by others with the aim to increase the stock of knowledge and its use to devise new and improved goods, services and processes; and (2) the acquisition of external knowledge which is defined as purchasing or licensing of patents and non-patented inventions, know-how and other types of knowledge from other organisations (Department of Trade and Industry, 2005). Whilst the expenditure data linked to these categories (given in Question 14) are sometimes less reliable, we can still use the yes and no responses to Question 13 to establish whether firms have undertaken these "open innovation" activities over the period (2002-2004). Such

activities have been described in the literature as evidence of "markets for technology" (Arora et al., 2001, Arora et al., 2002).

The second of the two lesser used metrics is the recorded "authorship" of innovation in the Survey. In the UK Innovation Survey, respondents record whether they have undertaken product (good or service) and/or process innovation (Questions 5 and 9). Linked to these questions are further questions about how the product or process innovations were developed (Questions 6 and 10). Product or Process innovators can select from three mutually exclusive options: "mainly by your enterprise or enterprise group; mainly by your enterprise together with other enterprises or institutions; and mainly by other enterprises or institutions" (Department of Trade and Industry, 2005). Some scholars have chosen to limit their interpretation of "open innovation" strategies to collaboration, and therefore they would be addressing only the second of these options, which relates to collaboration. However, we would argue that both the second and the third options reflect strategies engendered by the open innovation model. Chesbrough and Crowther describe this as "inbound open innovation", "…the practice of leveraging the discoveries of others: companies need not and indeed should not rely exclusively on their own R&D."(Chesbrough and Crowther, 2006: 229) In his most recent article, Chesbrough describes several company histories, amongst which he includes the "Connect and Develop" programme at Proctor & Gamble (P&G), through which P&G licenses or acquires products from other companies and brings them to market under the P&G brand (Chesbrough, 2007). In our reading of the open innovation literature, this differentiation is fundamental; external sources of knowledge and technology are not only important as complements or contributions to the innovation process through collaboration, but they are equally important as substitutes for internal and direct collaborative effort.

The discussion thus far has provided several measures by which we could define the "openness" of a firm in its innovation practices. Operationalising these as proxies in the UK Innovation Survey as suggested above, we can construct seven measures which capture different features of an "open innovation" approach in firms. These measures are defined in Table 1. From the literature, we cannot establish *a priori* which of these measures is the most meaningful proxy for openness. In order to identify which of these had the greatest potential for our empirical study, we first conducted a correlation analysis across the metrics for all respondents (16,445), looking at a subset of innovators (product and/or process) to compare all seven metrics, including the measures related to a specific recorded innovation. However, we did not want to limit ultimately our analysis to recorded innovators. Instead, our aim was to look at the responses of all firms demonstrating the various open innovation practices, regardless of the outcomes. The findings are presented and discussed in Sections 4 and 5.

< *Table 1* ***Descriptive values of Open Innovation Measures*** >

Our hypotheses aim to explore the importance of design and sectors in the expression of open patterns of innovation by firms. As such, we will use the *markets for technology* (Question 13) measure as our lead proxy for open patterns of innovation because it specifically addresses practices by the firm to acquire R&D and knowledge from external organisations for innovation. As such, this open innovation practice most closely approaches the division of an innovative task across firm boundaries. We will then use the proxies by sources of information and specified innovation-related metrics to test the robustness of our results in subsequent models.

In the Open Innovation literature, the degree of "openness" of a firm in its innovation practices has been operationalised in different ways. Typically, researchers identify the firm'sintent to more extensively use external sources of technology and knowledge. A lead practice for this intent is the practice of sourcing information (and potentially knowledge) from outside organisations, both in terms of breadth (range of sources) and depth (importance of sources). A second practice often studied is collaboration patterns by type and location of collaborator. Two further practices are possible to assess through the database: a direct measure of the external sourcing of knowledge and R&D and the authorship of a listed innovation. We look for the patterns of correlation and consistency across these measures to help define what we mean by "open".

3.2 Independent variables

Principal independent variables

We are aiming to test the association between "openness", design practices and sectors. The UK Innovation Survey collects information on design practices in four questions: one with respect to engagement in design activities, a second on design expenditures and two referring to the use of design as a means to protect innovation. The first of these, design activities, records where firms have engaged in design functions for the development or implementation of new or improved goods, services and processes. The guidance in the questionnaire explicitly requests firms to exclude for this category activities and expenditure on design in the R&D phase of product development (Department of Trade and Industry, 2005, Question 13). We will not use in this study the responses to expenditures on all forms of design (Question 14), as others have noted that the data are highly variable (Tether, 2006: 18). However, a comparison of respondents who indicated design activities and expenditures are highly correlated (0.84***), and so we will argue that using the design activities variable is sufficient to identify design-active firms in the sample.

The second two questions on design are presented as particular reasons for undertaking design, rather than an exploration of the many roles that design can play. The first of these is the use of design as a formal protection of innovation; that is, how does the firm see the importance of the registration of design. The second question is similar, but the emphasis is on the strategic (less formal) use of design for protection through complexity (Department of Trade and Industry, 2005, Question 21). Whilst these questions are capturing the role of design for protection, the effect is to identify firms who recognise the role of design in control for the innovation process. This is consistent in a view of design as a means for partitioning the innovative task and thereby defining areas of authority and control. In both questions, firms were asked to rank the role of design as "not used", "of low importance", "of medium importance" or "of high importance". The descriptive values of these independent variables are presented in Tables 2 and 3, where Table 2 provides simple count shares and Table 3 presents the summary statistics and correlation matrix for all of the independent variables discussed in this section.

< *Table 2* ***Number and shares of independent variables*** >

< *Table 3* ***Descriptive values of independent variables and proxies*** >

Sectoral differentiation is also explored in terms of industry classification as well as the

specialist CoPS categories. The CoPS classification is undertaken as follows. Firms engaged in the production of CoPS (e.g. gas turbines) and CoPS-based services (e.g. telecommunications) are identified at the 4-digit Standard Industrial Classification (SIC 92) level according to the classification for CoPS established in previous research (Acha et al, 2004). The classes selected are reproduced here in Appendix 1. For sectoral classification, we follow the broad categories established by the UK Department of Trade and Industry (Department of Trade and Industry, 2006: 59). These sectors are defined as: primary, engineering-based manufacturing, other manufacturing, construction, retail & distribution, knowledge-intensive services and other services. Table 2 indicates the SIC (92) codes that each of these categories includes.

In addition to the sectoral classifications, we also include a measure to capture uncertainty in demand for innovative goods and services. This market uncertainty proxy is difficult to capture as a variable, as it is largely based on perception rather than recordable figures. In Podolny's study (1994), market uncertainty was established in the research setting itself (the non-investment grade debt market). Many scholars have followed a similar approach (selecting the research setting) to explore the impacts of market uncertainty. In this study, we are looking across the economy to explore patterns in firm behaviour and response, and therefore we do not select the research setting for market uncertainty. Rather, we have to rely on proxies for market uncertainty. The UK Innovation Survey includes some information on how firm's perceive market uncertainty, but the question is framed as a "constraint" to innovation (Department of Trade and Industry, 2005: Question 19). Firms were asked whether "uncertain demand for innovative goods or services" have acted as a constraint to innovative activities or influenced a decision not to innovate over the period 2002 – 2004. As in previous questions, firms were asked to rank the impact of "uncertain demand" as "not experienced", "of low importance", "of medium importance" or "of high importance". Most firms (15,722) answered this question, and over half of these firms indicated that they had experienced market uncertainty to some degree (see Table 2). Whilst this question is not an objective measure of market uncertainty, it does reflect the perception of the firm and perception may be the most relevant link to other firm choices (such as open practices).

Controls

Finally, we include three further independent variables to control for other factors which may affect open innovation practices: the size of the firm, the share of qualified scientists and engineers in the firm'sworkforce and the conduct of internal R&D (as a binary response). The size of the firm is proxied as the log of the number of employees in 2004, as provided in the database from the UK Office of National Statistics register data. We include the share of qualified scientists and engineers in the firm's workforce in 2004 (Department of Trade and Industry, 2005: Question 26) as a measure of absorptive capacity (Cohen and Levinthal, 1990, Cohen and Levinthal, 1989), as others have done in previous work on open innovation (Laursen and Salter, 2005).

We introduce internal R&D for the firm, but as a proxy ("Did your enterprise engage in intramural (in-house) R&D?"(Department of Trade and Industry, 2005: Question 13) rather than as a value. We chose not to use the value data because of relatively low response rate for this question (25.41%) the skewness of the results, including a few significant outliers. As a control variable, internal R&D was not at the centre of the analysis, and as such the proxy variable is sufficient for the purpose.

3.3 Models and method

We use a logit regression to explore the associations between the markets for technology measure with design, sectors and market uncertainty. Our first model regresses the markets for technology measure (as defined in section 3.1) on our key independent variables (design activities, registration of design, complexity of design and uncertainty of demand) and includes dummy proxies for CoPS production and CoPS-based service industries as well as our control variables. The second model tests the same relationship but with respect to the broad sectoral categories defined by the UK Department of Trade and Industry in place of the CoPS proxies. Unlike the CoPS proxies these proxies include all 16,445 respondents, and the construction sector is used as the reference category. Table 3 presents the descriptive values of the independent variables and their correlation matrix.

In light of our review of open innovation proxies, we then test the robustness of our findings by running the models with alternate open innovation proxies as the dependent variable. Using the depth and breadth metrics separately as dependent variables, we test their relationship with the design, sectoral and market uncertainty variables, as well as the control measures. The choice to use the depth and breadth metrics (rather than the collaboration measures) was made because depth and breadth were the most closely correlated to our main open innovation proxy (open innovation practices). We would anticipate that the relationship between the information sourcing variables and our explanatory variables would be similar in sign but perhaps not in scale. Because depth and breadth measures are count data (0-11), we use a zero-inflated poisson regression for this model, due to the preponderance of 0 values and supported by the Vuong test.[8] Models 3 and 4 regress breadth of information sourcing on the principal, sectoral and control variables, whilst Models 5 and 6 regress depth on these independent variables. Again, for the sectoral models, the construction sector serves as the reference category.

We test the association between "openness", design practices and sectors. The UK Innovation Survey database holds data on design activities as well as measures of design as a means to protect innovation. We use all three of these measures in the analysis. Market uncertainty is recorded at the firm level through respondent assessments in the survey. To capture differences across sectors, we categorise respondents in two ways. First we test respondents that are classified CoPS producers and CoPS-based services in accordance with previous research (Acha et al, 2004). We then group and test respondents using the seven broad industrial classifications used by the Department of Trade and Industry in its innovation analysis. Size of firm, share of qualified scientists and engineers in the workforce and internal R&D are used as controls in the models.

4 Results

4.1 The measures of "openness"

As described in Section 3, using the UK Innovation Survey we have constructed seven measures to capture different features of an "open innovation" approach in firms. We then conducted a correlation analysis across the "open innovation" measures for all

[8] The Vuong test results had z values of 64.11 for model 5 (pr>z=0.000), 64.04 for model 6 (pr>z=0.000), 27.06 for model 7 (pr>z=0.000) and 26.96 for model 8 (pr>z=0.000). Because of the significance of the z values, the results of an ordered logit model would be less reliable and therefore we used the zero inflated model instead.

respondents (16,445), looking at a subset of innovators (product and/or process) to compare all seven metrics, including the measures related to a specific recorded innovation as presented in Table 4. We then compared the five non-specific metrics for all respondents, as presented in Table 5.

<Table4 ***Correlation of open innovation metrics, product and process innovators****>*

<Table 5 ***Correlation of open innovation metrics, all respondents*** >

What strikes you immediately is the relatively low correlation between these different metrics.[9] Except where questions are linked (for example, in the breadth and depth measures and the choice options for the authorship of innovations (questions 6 and 10)), the relatively low correlations suggest that each metric is capturing a different group of firms exhibiting different open innovation styles. This has important implications at a theoretical and an operational level. At the theoretical level, the implications are that there are many facets of openness and we could anticipate the development of a typology of open innovation styles for firms and potentially sectors, although we have not tested for sectoral differentiation in these correlations.

Consider, for example, where innovations have been developed primarily by other enterprises or institutions (Authorship: external sources of innovation, Table 4). Firms that have introduced new or significantly improved products or processes developed mainly by other firms or organisation are significantly different in association with the other measures of openness. Not only is the correlation negative with those who have collaborated in that innovation (Authorship: collaboration) which would be expected as these are mutually exclusive choices, but the variable for externally developed innovations is negatively correlated (albeit weakly) with every other variable in Table 4, including patterns of collaboration and information sourcing. This suggests that this subset of firms has a very distinct profile of open innovation. As Chesbrough (2007) emphasises, the choice of firms to capitalise on the innovation efforts of others is part of the open innovation portfolio; however, it appears from this superficial review that this strategy may also have the potential to replace certain other activities suggested in open innovation approaches, such as collaboration and search. Certainly, this analysis suggests that further research is called for to tease out these different open innovation profiles and the factors upon which they hinge.

At an operational level, the implications are more immediate for this study. Having dropped the specified innovation-related metrics (Authorship: collaboration, Authorship: external courses for innovation) to broaden our sample, we record metrics in Table 5 for collaborative practices, external sourcing of R&D and knowledge (markets for technology measures) and sources of information. Again, the correlation is only high where questions are linked, as in the case of recorded collaboration (Question 17, Choice to collaborate) and the identification of external collaboration partners (Question 18). Likewise, the correlation between the breadth and depth measures of information sources is at a predictable level. However, across these three aspects of open innovation, correlation does not rise above 0.384 (external sourcing of R&D and knowledge and breadth of information sources). The implication for our study is that the choice of metric can have significant impacts on the results, because in essence

[9] Moreover, the Cronbach alpha (scale reliability) is 0.527 across the five metrics (all respondents) and 0.513 across the seven metrics (innovators), which again underscores the distinctiveness of these various open innovation practices.

each of these characteristics of openness selects a different subset of firms. Again, because our aim is to explore the importance of design and sectors in the expression of open patterns of innovation by firms, we use the *markets for technology* (Question 13) measure as our lead proxy for open patterns of innovation and the sources of information proxies to test the robustness of our results in subsequent models.

We find relatively low correlation and consistency (as measured by Cronbach's alpha) between the different measures of "openness". Except where questions are linked, the relatively low correlations suggest that each metric is capturing a different group of firms exhibiting different open innovation styles. This has important implications at a theoretical and an operational level. At the theoretical level, the implications are that there are many facets of openness and we could anticipate the development of a typology of open innovation styles for firms and potentially sectors. At an empirical level, the choice of "open" innovation measure will result in different statistical outcomes. For this study, we focus on the markets for technology measure (external acquisition of R&D and knowledge) as this has the most immediate link to open innovation practice, but we test the robustness of results against the models for information sourcing (breadth and depth).

The role of design

The results for all six models are presented in Tables 6 and 7. Overall, the models are significant and provide evidence in support of our two hypotheses, but to a greater extent with respect to the role of design in firms pursuing open patterns of innovation (Hypothesis 1). As discussed, we tested the robustness of the findings of models 1 and 2 by replacing open innovation practices as a dependent variable with two other related measures: breadth and depth in information sources. The patterns in the variables were broadly similar, although there were interesting distinctions in some of the external variables when depth was used as the dependent variable. We highlight these below.

All of the design variables are positively associated with open innovation practices and statistically significant in most cases. This confirms our hypothesis that design plays a relatively more important role in firms which pursue open innovation practices. Where the "markets for technology" measure (acquisition of R&D and knowledge) is used as the dependent variable, the firm's design activities are the most influential in the model, positively correlated and statistically significant. Design activities are also the most influential of the design variables in the model where breadth is the dependent variable. However, this is not the case where we model depth in information sources as the measure of open innovation practice (models 5 and 6). When we are associating design variables with depth in information sourcing, the use of design to control the innovation process through complexity and, to a lesser degree through registration, is most influential in the model. This confirms our earlier correlation analysis of open innovation metrics that there are different styles of open innovation practice.

< *Table* 6 ***Logit regression associating open innovation practices with design, market uncertainty and sectors***>

< *Table 7* ***Zero inflated poisson regression associating depth and breadth in information sourcing with design, market uncertainty and sectors*** >

We hypothesised that open patterns of innovation would vary by sector, reflecting

differences in market conditions, opportunity and organizational structures for innovation. Three of the models associated the likelihood of our open innovation measures (markets for technology (1), breadth (3) and depth (5)) with CoPS production and CoPS-based services. In all three models, CoPS-based services were positively and significantly associated with the innovation metrics, suggesting that being a CoPS-based services firm increased the likelihood of openness by these measures. The same was only true for CoPS production firms in the model where openness was proxied by breadth in information sourcing. Given that the CoPS literature has provided many examples of open innovation practices across networks of firms and users, we explored the characteristics of CoPS and CoPS-based firms further to identify reasons why the results for openness were so striking for CoPS-based services but not for CoPS production firms (Table 8).

Moreover, the relative share of CoPS production firms that sources innovation externally is clearly lower than the relative share for all other respondents and, notably, for CoPS-based services. In the manufacture and construction of CoPS, it would appear that the organisation of the innovation task is either done by the firm itself or with close collaborators. Although they have an even higher share of innovations sourced in-house and collaboratively, CoPS-based service firms also source their innovations externally more than CoPS production firms and all other respondents. However, we do not wish to overstate this pattern for external sourcing, which accounts for a small percentage of respondents overall.

< *Table 8* ***Analytical descriptives for CoPS*** >

Nevertheless, the significance of services, particularly knowledge-based services, is in evidence in many of the models. Of course, the analysis of the sectors must be read with respect to the reference sector, construction. For firms that acquire knowledge and R&D externally ("markets for technology" openness), there is clear differentiation across sectors although only one of these values is statistically significant (knowledge-intensive services).[10] Relative to the construction sector, the manufacturing sectors are less open by this measure; all other sectors are more open, with knowledge-intensive services standing out as both more open and statistically so. Using breadth of information sources as a measure of openness, the sectoral patterns are much different, with all sectors less open than the construction sector. Moreover, the relative values are statistically significant for four of the six sectors, excepting the knowledge-intensive services and primary sectors. The sectoral patterns change again with respect to the likelihood of firms which have deep patterns of information sourcing. In model 6, we find that the manufacturing sectors are significantly less likely than the construction sector to have deep information sourcing practices, whereas the knowledge-intensive services are significantly more likely. In very broad terms, we can draw from this analysis that styles or types of open innovation practice differ significantly across sector. Although a more detailed level of study would develop these findings further and indeed to test to what extent open styles are more an outcome of firm choice or of industry design, there is some evidence that the knowledge-intensive services sector demonstrates the strongest evidence of open innovation practice, which is also consistent with the CoPS analysis. Although Chesbrough and colleagues (Chesbrough and Crowther, 2006, Chesbrough et al., 2006, Chesbrough, 2003a) have frequently described open innovation strategies in product-based firms, our findings here indicate that the greater evidence points to

[10] In each of these models, we test the statistical significance for the variation across sectors, and in each case the Wald statistic is significant to the 1% level.

services as leading in open innovation practice.

We also explored the influence of uncertain demand for innovative goods and services, to see if this might encourage the coordination of tasks through agreed interfaces in some sectors, as it happens in CoPS-based firms. The relationship is positive, significant and robust when we proxy open innovation practice through the "markets for technology" measure and breadth in information sourcing. However, the pattern changes when we proxy open innovation practice by depth of information sourcing, where we find that greater demand uncertainty for innovative goods and services makes depth less likely. Where market uncertainty is present, we can suggest from this finding that the firm'sresponse is to look widely, rather than deeply.

We also controlled for firm size, the share of qualified scientists and engineers (QSEs) in the workforce and whether the firm undertakes in-house R&D. The notable finding was that the likelihood of a firm undertaking its own R&D as well as having open innovation practices was more strongly linked, as the theory would predict. This relationship was strongest where open innovation practice was modelled by the acquisition of R&D and knowledge ("markets for technology" measure), offering an interesting finding that external sourcing of knowledge and R&D does not imply a hollowing out of the firm's R&D, but rather underscores the importance of absorptive capacity ((Cohen and Levinthal, 1990, Cohen and Levinthal, 1989).

We find support for our hypotheses that open innovators need more developed design capabilities and that open patterns of innovation vary by sector and market conditions. We also find interesting differences between open innovation measures, with greater consistency between firms that acquire knowledge and R&D externally and firms that source information broadly, and less so with firms that attach greater importance to their external sources of information. For example, we find that greater demand uncertainty for innovative goods and services makes depth less likely. Where market uncertainty is present, we can suggest from this finding that the firm's response is to look widely, rather than deeply. Amongst the sectors, CoPS-based services and knowledge-based services demonstrate the greatest association with open patterns of innovation.

5 Discussion and conclusions

Using the UK Innovation Survey Database 2005, we have tested the importance of design and sectoral differentiation in open innovation practices. The two hypotheses have been supported by the data, and we can conclude that open innovation is not simply a matter of choice for the firm, but of design capacity and sectoral opportunity. Moreover, we can also conclude that open innovation is not a general tendency expressed in different ways. The term "open innovation" reflects a range of organisational behaviour, which finds meaning under different contexts of market and innovation dynamics. As the analysis of measures demonstrates, "open" is an umbrella term for the various means, depths and motives for reaching across organisational boundaries to achieve an innovation task.

5.1 The importance of design

Our analysis indicates that design provides the translation of understanding and expectation between organisations engaged in open innovation practices. The findings demonstrate that firms which actively undertake design activities for innovation and

which use design to control the innovation process, are more likely to also pursue open strategies for innovation, although these strategies may include different practices. We believe that the emphasis on design reflects the requirement for interfaces between partitioned innovation tasks, reflecting on the instrumental rather than aesthetic role of design. Design reflects in part the negotiated boundaries of innovation between organisations, which is essential for open innovation strategies to be productive.

Our analysis indicates that design is an important capability for open innovation practices, but further research is needed to explore the causality of the process. We cannot yet say whether design capabilities invoke open innovation practices, or if open innovation trends elicit design capabilities. It could be that design capabilities facilitate the open innovation process, making it more likely for firms and sectors with strong design capacities to adopt a more distributed process for innovation. However, capabilities research would imply that these open structures would have to have been in place for some considerable time to evoke capability development. Indeed, this would be consistent with the CoPS story as told through the qualitative research undertaken. However, in this study, we find that CoPS-based services are more likely to have open innovation practices than CoPS manufacturers. We also find that CoPS manufacturers are more design-focused. Clearly the link between design capacity and open innovation practice is neither simple nor direct, but an important line for future research.

5.2 Industrial organisation of open innovation

Our findings are robust in scale, but not in kind to the use of different measures for open innovation practices. Design activities are most likely where we proxy open innovation patterns with the “markets for technology” measure (acquisition of external knowledge and extramural R&D). For these firms, open innovation takes on a more supplier-client relationship, with the innovation task perhaps more clearly divided between organisations and perhaps typifying what Chesbrough (2003a) refers to as “inbound” innovation. This is evocative of the CoPS pattern of innovation recounted in the case histories. However, our findings here suggest a more differentiated pattern, in which firms that manufacture CoPS may have partitioned the innovation task so thoroughly as to limit their needs to acquire knowledge or R&D from external sources.

When we proxy open innovation practice by the breadth of information sources used by the firm, we find similar (albeit weaker) relationships and significance for the importance of design activities and the use of design to control innovation. Being open to a wide range of information from different sources is clearly a different style or type of open innovation practice. Sourcing information is not necessarily indicative of task partitioning for an innovation, although it may certainly lead to this. The firm that demonstrates great breadth in information sourcing may be revealing an absorptive strategy with its wider industrial network) prompted by sectoral conditions, including market uncertainty which had an even higher relative probability of co-occurrence in these models. This suggests that where market uncertainty is present, firm response to look widely rather than deeply.

Why, then, does the probable co-occurrence of design activities and open innovation practice disappear when we proxy the latter according to depth in information sourcing? In contrast, the measures for the use of design as a means to control the innovation process retain their relationship and significance with the dependent variable. We infer from these findings that firms that pursue deep information sourcing patterns with many types of organisations suggest a pattern of closed (or tightly

defined) networks for innovation, where control measures are emphasised (e. g. complexity, registration of design). These firms may be those engaged in selling R&D and knowledge to others, as Chesbrough (2003a) describes as "outbound" innovation. However, we can say relatively little about the partitioning of the innovative task for these firms. As in the case of CoPS manufacturers[11], the innovative task may be very fully partitioned, limiting the need for external suppliers of knowledge and R&D. The design activities variable is positive and significant in the sectoral (rather than the CoPS) model. There is further work to be done to disentangle these results to say anything more conclusive.

Moreover, we can propose from these results (to be tested in further research) that firms that actively undertake to acquire knowledge and R&D externally share some characteristics of openness with firms who maintain a broad sourcing pattern for information. These firms are active "hunter/gatherers" when it comes to innovation and their frame of view is relatively wide. Firms with depth in information sourcing may maintain open innovation practices, but within a more constrained network of known and trusted partners. The relative importance of design to control the innovation process would be consistent with such a pattern.

Knowledge-intensive services (which would include CoPS-based services as well) stand out in our analysis as leading sectors for open innovation practices. This is a new insight for the open innovation discussion, as very little analysis has been done on open innovation practices in the services. Although we do not explore this relationship further in this paper, we would test in further research whether this association may be an outcome of differences in the nature of the innovation task in these markets. Indeed, such a study would also complement the growing research into innovation in services. Moreover, given the growing importance of these sectors (in value terms) to developed economies, a growing focus on open innovation practices for innovation for policy makers, as well as scholars, is understandable and expected.
We have demonstrated, using even very blunt industrial categories, that there is sectoral variation in open innovation practices. Given what we know from the many studies done on sectoral patterns of technology and innovation (including the Pavitt taxonomy (1984)) and their origins (Peneder, 2003), this is not surprising. However, our findings do suggest an opportunity to revisit these sectoral classifications from a more faceted understanding of the organisation of innovation and the potential for open innovation practices. In general, these characterisations are still centred primarily on "who" develops technology, rather than "how" (the practices by which) the innovation task is carried out. Instead of identifying the critical source of technological change in sectors and the characteristics of these actors, we can anticipate exploring the choices and opportunities for firms to organise the innovation task in that sector. Moreover, instead of labelling the predominant character of technological innovation for the sector, we can perhaps refine our understanding by exploring the nature of the innovative task, the drivers and potential for its partitioning, and how these dynamics are conditioned by the wider industrial environment.

[11] We find that whilst all CoPS firms (production and CoPS-based services) generally collaborate more than all other respondents and are more active in their sourcing of information, they are also more likely for their innovations to be undertaken in-house. This implies a different style of openness, where collaboration and information sourcing is not necessarily linked to a specific innovation task. We also note that all CoPS firms have higher levels of design activities than other respondents, and that a higher share of CoPS firms collaborates on their innovations.

As the analysis of measures demonstrates, "open" is an umbrella term for the various means, depths and motives for reaching across organisational boundaries to achieve an innovation task. Design provides the translation of understanding and expectation between organisations engaged in open innovation practices. The findings demonstrate that firms which actively undertake design activities for innovation and which use design to control the innovation process, are more likely to also pursue open strategies for innovation, although these strategies may include different practices. Our findings are robust in scale, but not in kind to the use of different measures for open innovation practices, and we elaborate emergent typologies suggested in the sectoral variation. Knowledge-intensive services (which would include CoPS-based services as well) stand out in our analysis as leading sectors for open innovation practices. This is a new insight for the open innovation discussion, as very little analysis has been done on open innovation practices in the services. Overall, this research suggests that we can refine our understanding by exploring the nature of the innovative task, the drivers and potential for its partitioning, and how these dynamics are conditioned by the wider industrial environment.

5.3 Limitations of this research

There are several limitations to this study, some of which have already been mentioned. Because this is a cross-sectional study rather than a longitudinal study, we can draw no conclusions about the causality or sequencing of design capacity and open innovation practices. Also, our measures of design as a means to control the innovation process are part of a wider set of questions about protection methods for innovation, rather than design per se. We may be capturing in these responses a more general intention to protect innovation than to acknowledge the value of design. Moreover, our design variables relate to design in general and not specifically the interface role for design. Finally, we do not have any data in the survey to provide evidence on whether design capacity improves innovation outcomes for firms following an open innovation model. A clearer understanding of this specific role for design and the innovation task partitioning it supports will require further and deeper qualitative research.

In addressing the sectoral variation of open innovation practices, further research is necessary to better identify patterns of open innovation and contributing factors at a more disaggregated level. In this study, we have used sectoral categories established by the UK Department of Trade and Industry as a first attempt to answer this research question, as these sectors are relevant for policy makers. However, these broad sectors combine many very different markets and industrial structures that obscure the occurrence of open innovation practices and make it impossible to define sectoral characteristics that might account for these patterns, as we did for CoPS with the advantage of many detailed case studies.

Whilst our findings support our hypotheses and in particular the relevance of design capacity, this research cannot reveal the organisational dynamics of innovation task partitioning where open innovation involves collaborative or externally sourced innovation. This may be another route to the role of the systems integrator, found in both CoPS and non-CoPS examples. (Hobday et al., 2005, Prencipe et al., 2003) Design may also have some defining role with respect to the ownership of intellectual property rights, and this may provide further insight for our measures of design to control the innovation process (registration of design and complexity of design). Other authors have noted that the open innovation model does not adequately deal with the "potential difficulty of appropriating the returns to innovation when technological

development is more widely dispersed." (Helfat and Quinn, 2006: 87) Future research should consider whether design acts as a means of demarcating or shoring up control over intellectual property rights across organisations engaged in "open", distributed innovation.

6 Policy recommendations

This study has highlighted the role of design capacity as a core capability for open innovation practice, and as such, managers and policy makers should pay greater attention to the role of design capacity in extramural, open innovation, achieved either through collaboration or through contract. Moreover, this research presents further evidence that our understanding of the role and nature of design is still woefully lacking, in comparison to the substantial work completed on defining and characterising R&D, science, technology and even innovation itself. Our emphasis on design reflects the requirement for interfaces between partitioned innovation tasks, reflecting on the instrumental rather than aesthetic role of design. However, this designation may be premature and to some extent artificial. Further research is needed to advance our understanding of design in the innovation process.

Policy makers and managers must also be aware that the choice to follow an open innovation strategy requires more than willing. Necessary capabilities within the firm must be in place to support the nature of the innovation task solved in this open arena. If the task is to scan new ideas and technologies, capabilities to source information and collaborate on innovative activities are most important. If the task is divided across organisations, design capacity may prove a necessary capability. However, this organisation of the innovation task is also condition by sectoral conditions. As such, policies for open innovation cannot be uniform across firms and industries, and this is frustrated further by the different styles of open innovation practice that we explored in this study. There is clearly no "one size fits all" policy to support open innovation, and there is no single interpretation of open innovation practice. We have suggested here that the different styles or expressions of open innovation practice may be related to the nature of the innovation task, and if so, then further work is necessary to develop this typology to provide more conditional advice to policy makers and managers.

This study has highlighted the role of design capacity as a core capability for open innovation practice, and as such, managers and policy makers should pay greater attention to the role of design capacity in extramural, open innovation, achieved either through collaboration or through contract. Moreover, this research presents further evidence that our understanding of the role and nature of design is still woefully lacking, in comparison to the substantial work completed on defining and characterising R&D, science, technology and even innovation itself. Moreover, this study suggests that openness as an innovative strategy is not a panacea nor a simple choice, for the firm or the policy maker.

References

ACHA, V., DAVIES, A., HOBDAY, M. & SALTER, A. (2004) Exploring the capital goods economy: complex product systems in the UK. *Industrial and Corporate Change,* 13**,** 505-529.

ARORA, A., FOSFURI, A. & GAMBARDELLA, A. (2001) Markets for Technology and their Implications for Corporate Strategy. 10**,** 419-451.

ARORA, A., FOSFURI, A. & GAMBARDELLA, A. (2002) *Markets for Technology: The Economics of Innovation and Corporate Strategy,* Cambridge, MA, MIT Press.

BALDWIN, C. Y. & CLARK, K. (1997) Managing in an age of modularity. *Harvard Business Review,* 75**,** 84-93.

BECKER, M. & ZIRPOLI, F. (2007) Coordinating innovation in networks: From task decomposition by product architecture to replicating template platforms. *DRUID Summer Conference 2007 on Appropriability, Proximity, Routines and Innovation.* Copenhagen, DRUID.

BRESCHI, S., MALERBA, F. & ORSENIGO, L. (2000) Technological regimes and Schumpeterian patterns of innovation. *Economic Journal,* 110**,** 388-410.

BRUSONI, S. & PRENCIPE, A. (2006) Making Design Rules: A Multidomain Perspective. *Organization science,* 17**,** 179.

BRUSONI, S., PRENCIPE, A. & PAVITT, K. (2001) Knowledge specialization, organizational coupling, and the boundaries of the firm: Why do firms know more than they make? *Administrative Science Quarterly,* 46**,** 597-621.

CARLSSON, B. & JACOBSSON, S. (1994) Technological Systems and Economic-Policy - the Diffusion of Factory Automation in Sweden. *Research Policy,* 23**,** 235-248.

CHESBROUGH, H. (2003a) *Open Innovation: The New Imperative for Creating and Profiting from Technology,* Boston, MA, Harvard Business School Press.

CHESBROUGH, H. (2004) Managing open innovation. *Research-Technology Management,* 47**,** 23-26.

CHESBROUGH, H. & CROWTHER, A. K. (2006) Beyond high tech: early adopters of open innovation in other industries. *R & D Management,* 36**,** 229-236.

CHESBROUGH, H. W. (2003b) The era of open innovation. *Mit Sloan Management Review,* 44**,** 35-41.

CHESBROUGH, H. W. (2007) Why companies should have open business models. *Mit Sloan Management Review,* 48**,** 22-+.

CHESBROUGH, H. W., VANHAVERBEKE, W. & WEST, J. (Eds.) (2006) *Open Innovation: Researching a New Paradigm,* Oxford and New York, Oxford University Press.

CHRISTENSEN, J. F., OLESEN, M. H. & KJAER, J. S. (2005) The industrial dynamics of Open Innovation - Evidence from the transformation of consumer electronics. *Research Policy,* 34**,** 1533-1549.

COHEN, W. M. & LEVINTHAL, D. A. (1989) Innovation and Learning - the 2 Faces of R-and-D. *Economic Journal,* 99**,** 569-596.

COHEN, W. M. & LEVINTHAL, D. A. (1990) Absorptive-Capacity - a New Perspective on Learning and Innovation. *Administrative Science Quarterly,* 35**,** 128-152.

COOMBS, R., HARVEY, M. & TETHER, B. (2001) Analysing Distributed Innovation Processes. *Centre for Research on Innovation & Competition.* Manchester, University of Manchester.

COOMBS, R., HARVEY, M. & TETHER, B. S. (2003) Analysing distributed processes of provision and innovation. *Industrial and Corporate Change,* 12**,** 1125-1155.

DAHLANDER, L. & GANN, D. (2007) How Open is Innovation? *DRUID Summer Conference 2007 on Appropriability, Proximity, Routines and Innovation.* Copenhagen, DRUID.

DAVIES, A. & BRADY, T. (2000) Organisational capabilities and learning in complex product systems: towards repeatable solutions. *Research Policy,* 29**,** 931-953.
DEPARTMENT OF TRADE AND INDUSTRY (2005) UK Innovation Survey. Department of Trade and Industry,.
DEPARTMENT OF TRADE AND INDUSTRY (2006) Innovation in the UK: Indicators and Insights. Department of Trade and Industry.
DODGSON, M., GANN, D. & SALTER, A. (2005) *Think, play, do,* Oxford and New York, Oxford Univ. Press.
DODGSON, M., GANN, D. & SALTER, A. (2006) The role of technology in the shift towards open innovation: the case of Procter & Gamble. *R & D Management,* 36**,** 333-346.
EDQUIST, C. (Ed.) (1997) *Systems of Innovation: Technologies, Institutions and Organizations,* Abingdon, Oxford, Routledge.
GANN, D. (2005) Book Review: H. Chesbrough, Open Innovation: The New Imperative For
Creating And Profiting From Technology, Harvard Business School Press,
2003 (272 pp., $35.00, ISBN: 1-57851-837-7). *Research Policy,* 34**,** 122-123.
HELFAT, C. E. & QUINN, J. B. (2006) Open innovation: The new imperative for creating and profiting from technology. *Academy of Management Perspectives,* 20**,** 86-88.
HOBDAY, M. (1998) Product complexity, innovation and industrial organisation. *Research Policy,* 26**,** 689-710.
HOBDAY, M., DAVIES, A. & PRENCIPE, A. (2005) Systems integration: a core capability of the modern corporation. *Industrial and Corporate Change,* 14**,** 1109-1143.
HOBDAY, M. & RUSH, H. (1999) Technology management in complex product systems (CoPS) - ten questions answered. *International Journal of Technology Management,* 17**,** 618-638.
HOBDAY, M., RUSH, H. & TIDD, J. (2000) Innovation in complex products and system. *Research Policy,* 29**,** 793-804.
JACOBIDES, M. G. & HITT, L. M. (2005) Losing sight of the forest for the trees? Productive capabilities and gains from trade as drivers of vertical scope. *Strategic Management Journal,* 26**,** 1209-1227.
JACOBIDES, M. G. & WINTER, S. G. (2005) The co-evolution of capabilities and transaction costs: explaining the institutional structure of production. *Strategic Management Journal,* 26**,** 395-413.
KATILA, R. (2002) New product search overtime: Past ideas in their prime? *Academy of Management Journal,* 45**,** 995-1010.
KATILA, R. & AHUJA, G. (2002) Something old, something new: A longitudinal study of search behavior and new product introduction. *Academy of Management Journal,* 45**,** 1183-1194.
LANGLOIS, R. (2002) Modularity in technology and organization. *Journal of Economic Behavior & Organization,* 49**,** 19-37.
LAURSEN, K. & SALTER, A. (2005) The Paradox of Openness: Appropriability and the Use of External Sources of Knowledge for Innovation. *Academy of Management Annual Meeting.* Honolulu, Hawaii, Academy of Management.
LAURSEN, K. & SALTER, A. (2006) Open for innovation: The role of openness in explaining innovation performance among UK manufacturing firms. *Strategic Management Journal,* 27**,** 131-150.
LEIPONEN, A. & HELFAT, C. E. (2005) Innovation Objectives, Knowledge Sources and the Benefits of Breadth. Ithaca, Cornell University.
MALERBA, F. (2002) Sectoral systems of innovation and production. *Research Policy,* 31**,** 247-264.

MALERBA, F. & ORSENIGO, L. (1996) Schumpeterian patterns of innovation are technology-specific. *Research Policy,* 25**,** 451-478.
MARSILI, O. & SALTER, A. (2006) The Dark Matter of Innovation: Design and Innovative Performance in Dutch Manufacturing1. *Technology analysis & strategic management,* 18**,** 515-534.
MCKELVEY, M., ALM, H. & RICCABONI, M. (2003) Does co-location matter for formal knowledge collaboration in the Swedish biotechnology-pharmaceutical sector? *Research Policy,* 32**,** 483-501.
MILLER, W. L. & MORRIS, L. (1999) *4th Generation R&D: Managing Knowledge, Technology, and Innovation*, John Wiley.
NOBELIUS, D. (2004) Towards the sixth generation of R&D management *International Journal of Project Management,* 22**,** 369-375.
OECD (2005) *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data, 3rd Edition,* Paris, DSTI, Organisation of Economic Co-operation and Development.
PAVITT, K. (1984) Sectoral patterns of technical change: Towards a taxonomy and a theory. *Research Policy,* 13**,** 343-373.
PENEDER, M. (2003) Industry Classifications: Aim, Scope and Techniques. *Journal of Industry, Competition and Trade,* 3**,** 109-129.
PODOLNY, J. M. (1994) Market Uncertainty and the Social Character of Economic Exchange. *Administrative Science Quarterly,* 39**,** 458-483.
PRENCIPE, A., DAVIES, A. & HOBDAY, M. (2003) *The Business of Systems Integration,* Oxford and New York, Oxford University Press.
ROGERS, D. M. A. (1997) The Challenge of Fifth Generation R&D. *Journal of Product Innovation Management,* 14**,** 133-134.
ROTHWELL, R. (1994) Towards the fifth-generation innovation process. *International Marketing Review,* 11**,** 7-31.
ROTHWELL, R. & GARDINER, P. (1983) The role of design in product and process change. *Design Studies,* 4**,** 161-169.
SANCHEZ, R. & MAHONEY, J. T. (1996) Modularity, Flexibility, and Knowledge Management in Product and Organization Design. *Strategic Management Journal,* 17**,** 63-76.
SIMON, H. A. (1996) *The Sciences of the Artificial*, MIT Press.
TETHER, B. (2006) Design in Innovation: Coming out from the Shadow of R&D. IN INNOVATION, O. O. S. A. (Ed.) *DTI Economic Series.* London, Department of Trade and Industry.
VINCENTI, W. G. (1990) *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History,* Baltimore and London, The Johns Hopkins University press.
VON HIPPEL, E. (1990) Task Partitioning - an Innovation Process Variable. *Research Policy,* 19**,** 407-418.
VON HIPPEL, E. & VON KROGH, G. (2003) Open source software and the "private-collective" innovation model: Issues for organization science. *Organization Science,* 14**,** 209-223.
WAGNER, H. E. (1991) The Open Corporation. *California Management Review,* 33**,** 15.
WALSH, V., ROY, R., BRUCE, M. & POTTER, S. (1992) *Winning By Design: Technology, Product Design and International Competitiveness* Oxford, Basic Blackwell.
WHYTE, J., BESSANT, J. R. & NEELY, A. D. (2005) Management of Creativity and Design Within the Firm. UK Department of Trade and Industry

Table 1 **Open Innovation Metrics: descriptives**

For Product and Process Innovators

	Observations	Mean	Std. Dev.	Min	Max
Authorship: collaborate to innovate (product or process) [Q6, 10]	5843	0.284	0.451	0	1
Authorship: external sources used to innovate (product or process) [Q6, 10]	5843	0.134	0.341	0	1
Collaborative practice [Q17]	5842	0.315	0.465	0	1
Collaboration with external partners [Q18]	5843	0.985	1.741	0	6
Markets for technology measure (Acquisition of external R&D and knowledge) [Q13]	5843	0.393	0.488	0	1
Breadth in sources [Q16]	5843	7.911	2.851	0	11
Depth in sources [Q16]	5843	1.895	1.785	0	11

For all respondents					
Collaborative practice [Q17]	15753	0.155	0.362	0	1
Collaboration with external partners [Q18]	16445	0.460	1.286	0	6
Markets for technology measure (Acquisition of external R&D and knowledge) [Q13]	16445	0.201	0.401	0	1
Breadth in sources [Q16]	16445	5.404	4.119	0	11
Depth in sources [Q16]	16445	1.104	1.619	0	11

Table 2 Number and shares of independent variables

	Respondents	Share of Total Respondents
TOTAL	16,445	
Design responses		
(Q13) Design activities (Yes/No)	*15,803*	
Yes	2,942	18.6%
(Q21) Importance of registration of design as a strategic (0-3, no to high importance)	*15,705*	
No importance	12,284	78.2%
Low importance	1,355	8.63%
Medium importance	1,115	7.1%
High importance	951	6.1%
(Q21) Importance of complexity of design as a strategic (0-3, no to high importance)	*15,706*	
No importance	10,536	67.1%
Low importance	2,241	14.3%
Medium importance	1,987	12.7%
High importance	942	6.0%
(Q19) Market uncertainty	*15,722*	
Not experienced	7,581	48.2%
Low	3,662	23.3%
Medium	3,213	20.4%
High	1,266	8.1%
Broad Sectoral categories		
Complex Products and Systems (CoPS)	2,552	15.5%
- *CoPS Production (manufacturing & construction)*	*986*	*6%*
- *CoPS-based services*	*1,566*	*9.5%*
Primary sector (SIC 10 – 14, 40 – 41)	233	1.4%
Engineering-based Manufacturing (SIC 28 – 35)	2,167	13.2%
Other Manufacturing (SIC 15 – 27, 36 – 37)	2,758	16.8%
Construction (SIC 45)	1,613	9.8%
Retail & Distribution (SIC 50 – 52)	2,889	17.6%
Knowledge-intensive services (SIC 64.2, 65-67, 72-73, 74.1 – 74.4)	2,799	17.0%
Other services (SIC 55, 60 – 64.1), 70-71, 74.5 – 74.8)	3,986	24.2%

Note: DTI Sectors of Industry are defined by the SIC(92), see "innovation in the UK: Indicators and Insights", *DTI Occasional Paper No. 6* (2006).

Table 3 Descriptive values of independent variables and proxies

		Obs	Mean	Std. Dev.	Min	Max	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Design activities	A	15803	0.186	0.389	0	1	1																	
Registration of Design	B	15705	0.410	0.864	0	3	0.32 ***	1																
Complexity of Design	C	15706	0.576	0.926	0	3	0.40 **	0.59 ***	1															
Breadth	D	16445	5.404	4.119	0	11	0.35 ***	0.38 ***	0.47 ***	1														
Depth	E	16445	1.104	1.619	0	11	0.29 ***	0.28 ***	0.38 ***	0.54 ***	1													
Uncertain demand	F	15722	2.159	1.228	1	4	0.26 ***	0.30 ***	0.38 ***	0.53 ***	0.26 ***	1												
CoPS (production)	G	16445	0.060	0.237	0	1	0.07 ***	0.03 ***	0.07 ***	0.04 ***	0.02 **	0.02 ***	1											
CoPS (based services)	H	16445	0.095	0.294	0	1	0.03 ***	0.03 ***	0.13 ***	0.11 ***	0.10 ***	0.07 ***	-0.08 ***	1										
Primary	I	16445	0.014	0.118	0	1	-0.01	-0.02 **	-0.02 **	-0.02 **	-0.02 **	-0.02 ***	-0.03 ***	-0.04 ***	1									
Engineering-based manufacturing	J	16445	0.132	0.338	0	1	0.18 ***	0.15 ***	0.20 ***	0.10 ***	0.05 ***	0.10 ***	0.28 ***	-0.13 ***	-0.05 ***	1								
Other manufacturing	K	16445	0.168	0.374	0	1	0.10 ***	0.13 ***	0.13 ***	0.10 ***	0.04 ***	0.11 ***	-0.11 ***	-0.15 ***	-0.05 ***	-0.17 ***	1							
Construction	L	16445	0.098	0.297	0	1	-0.07 ***	-0.08 ***	-0.10 ***	-0.05 ***	-0.07 ***	-0.07 ***	0.34 ***	-0.11 ***	-0.04 ***	-0.13 ***	-0.15 ***	1						
Retail & Distribution	M	16445	0.176	0.381	0	1	-0.10 ***	-0.05 ***	-0.11 ***	-0.09 ***	-0.05 ***	-0.07 ***	-0.12 ***	-0.15 ***	-0.06 ***	-0.18 ***	-0.21 ***	-0.15 ***	1					
Knowledge-intensive services	N	16445	0.170	0.376	0	1	0.01	-0.01	0.09	0.08	0.09	0.04	-0.11	0.62	-0.05	-0.18	-0.20	-0.15	-0.21	1				
Other services	O	16445	0.242	0.429	0	1	-0.11 ***	-0.12 ***	-0.17 ***	-0.12 ***	-0.06 ***	-0.10 ***	-0.14 ***	-0.10 ***	-0.07 ***	-0.22 ***	-0.25 ***	-0.19 ***	-0.26 ***	-0.26 ***	1			
Size (log employment)	P	16445	4.021	1.503	2.197	11.038	0.14 ***	0.19 ***	0.19 ***	0.21 ***	0.16 ***	0.11 ***	-0.01	-0.04 ***	-0.02 **	-0.02 ***	0.04 ***	-0.10 ***	0.01	-0.03 ***	0.08 ***	1		
Share of QSEs	Q	16439	6.205	28.739	0	896	0.06 ***	0.06 ***	0.12 ***	0.11 ***	0.08 ***	0.07 ***	0.03 ***	0.21 ***	0.02 **	0.01 *	-0.04 ***	-0.02 ***	-0.04 ***	0.16 ***	-0.06 ***	-0.01	1	
Own R&D	R	15803	0.315	0.465	0	1	0.45 ***	0.32 ***	0.46 ***	0.45 ***	0.36 ***	0.33 ***	0.04 ***	0.11 ***	-0.01	0.15 ***	0.15 ***	-0.13 ***	-0.13 ***	0.10 ***	-0.13 ***	0.152 ***	0.098 ***	1

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 4 **Correlation of open innovation metrics, product and process innovators**

Pearson correlation	**Authorship: collaboration [Q6, Q10]**	**Choice to collaborate [Q17]**	**External collaboration [Q18]**	**Authorship: external sources [Q6, Q10]**	**Markets for technology measure** (Acquisition of external R&D and knowledge) **[Q13]**	**Breadth in sources (all used) [Q16]**	**Depth in sources (used intensively) [Q16]**
Authorship: collaboration	1						
Choice to collaborate	.176***	1					
External collaboration	.170***	.834***	1				
Authorship: external sources of innovation	-.173***	-.060***	-.058***	1			
Markets for Technology measure	.138***	.238***	.271***	-.048***	1		
Breadth	.075***	.221***	.279***	-.096***	.258***	1	
Depth	.064***	.202***	.241***	-.068***	.176***	.385***	1

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 5 **Correlation of open innovation metrics, all respondents**

Pearson correlation	**Choic to collaborate [Q17]**	**External collaboration [Q18]**	**Markets for Technology measure** (acquisition of R&D and knowledge from external sources) **[Q13]**	**Breadth [Q16]**	**Depth [Q16]**
Choice to collaborate	1				
External collaboration	.854***	1			
Markets for Technology measure	.299***	.312***	1		
Breadth	.296***	.303***	.384***	1	
Depth	.278***	.290***	.309***	.535***	1

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 6 Logit regression associating open innovation practices with design, market uncertainty and sectors (reporting co-efficients)

	Model 1	Model 2
Design activities	**1.076**	**1.111**
	[20.53]***	[20.96]***
Registration of Design	**0.101**	**0.116**
	[3.78]***	[4.30]***
Complexity of Design	**0.144**	**0.16**
	[5.16]***	[5.68]***
Uncertain demand	**0.185**	**0.189**
	[9.36]***	[9.56]***
CoPS (production)	**-0.029**	
	[0.31]	
CoPS-based services	**0.224**	
	[3.05]***	
Primary		**0.083**
		[0.39]
Engineering-based manufacturing		**-0.152**
		[1.45]
Other manufacturing		**-0.112**
		[1.11]
Retail & Distribution		**0.071**
		[0.69]
Knowledge-intensive services		**0.283**
		[2.83]***
Other services		**0.165**
		[1.68]*
Construction *(reference category)*		
Size (log employment)	**0.075**	**0.067**
	[5.02]***	[4.48]***
Share of QSEs	**0**	**-0.001**
	[0.43]	[0.69]
Own R&D	**1.355**	**1.379**
	[26.78]***	[26.72]***
Constant	**-3.141**	**-3.196**
	[39.23]***	[29.20]***
Observations	**15671**	**15671**
Log-likelihood	**-6350.89**	**-6332.54**
LR (chi2) test	**3406.88*****	**3443.59*****

Absolute value of z statistics in brackets, * significant at 10%; ** significant at 5%; *** significant at 1%

Wald F Tests of statistical difference between sectoral coefficients in Model 2 has a $Chi^2(5) = 45.06$, prob(χ^2) = 0.000.

Table 7 Zero inflated poisson regression associating depth and breadth in information sourcing with design, market uncertainty and sectors

	Model 3	Model 4	Model 5	Model 6
	Breadth	**Breadth**	**Depth**	**Depth**
Design activities	0.052	0.052	0.027	0.046
	[6.13]***	[6.18]***	[1.38]	[2.32]**
Registration of Design	0.036	0.037	0.048	0.054
	[8.89]***	[9.05]***	[5.39]***	[6.03]***
Complexity of Design	0.054	0.055	0.083	0.093
	[12.61]***	[12.88]***	[8.70]***	[9.69]***
Uncertain demand	0.085	0.085	-0.035	-0.035
	[28.42]***	[28.55]***	[4.60]***	[4.49]***
CoPS (production)	0.045		-0.02	
	[3.30]***		[0.60]	
CoPS-based services	0.078		0.104	
	[7.15]***		[4.20]***	
Primary		-0.047		-0.122
		[1.47]		[1.42]
Engineering-based manufacturing		-0.079		-0.14
		[5.33]***		[3.60]***
Other manufacturing		-0.079		-0.093
		[5.59]***		[2.44]**
Retail & Distribution		-0.096		0.034
		[6.61]***		[0.87]
Knowledge-intensive services		-0.019		0.074
		[1.37]		[1.99]**
Other services		-0.09		0.023
		[6.53]***		[0.61]
Construction (reference category)				
Size (log employment)	0.036	0.036	0.048	0.044
	[15.98]***	[16.14]***	[9.17]***	[8.49]***
Share of QSEs	0.001	0.001	0.001	0.001
	[4.71]***	[5.18]***	[4.38]***	[4.23]***
Own R&D	0.072	0.075	0.154	0.172
	[9.27]***	[9.45]***	[8.18]***	[9.03]***
Constant	1.516	1.586	0.372	0.381
	[125.51]***	[101.86]***	[11.77]***	[8.89]***
Observations	15671	15671	15671	15671
log-likelihood	-34042.02	-34023.69	-20978.26	-20943.83

LR (chi2) test	3494.43***	3531.09***	603.57***	672.44***

Absolute value of z statistics in brackets, * significant at 10%; ** significant at 5%; *** significant at 1%

Wald F Tests of statistical difference between sectoral coefficients in Model 4 has a $Chi^2(5) = 38.22$, $prob(\chi^2) = 0.000$.

Wald F Tests of statistical difference between sectoral coefficients in Model 6 has a $Chi^2(5) = 87.15$, $prob(\chi^2) = 0.000$.

Table 8 Analytical descriptives for CoPS

	All CoPS production			**All CoPS-based services**			**All other respondents**		
	Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.
Innovations done in-house	986	0.28	0.45	1566	0.39	0.49	13893	0.22	0.42
Collaborate to innovate ***(Authorship:collaboration)***	986	0.12	0.33	1566	0.14	0.35	13893	0.09	0.29
External sources for innovation (Authorship: external sources of innovation)	986	0.02	0.15	1566	0.06	0.23	13893	0.05	0.21
In-house R&D activities ***(Own R&D)***	947	0.39	0.49	1512	0.47	0.50	13344	0.29	0.45
Design activities	947	0.29	0.45	1512	0.22	0.42	13344	0.17	0.38
Breadth	986	6.04	4.30	1566	6.77	4.05	13893	5.20	4.08
Depth	986	1.22	1.72	1566	1.58	1.82	13893	1.04	1.58

Appendix 1 Complex products and systems: extension on the classification established in Acha et al (2004)

Respondents in UK Innovation Survey 2005	SIC(92)	Description
16	2953	Manufacture of machinery for food, beverage and tobacco processing
4	2954	Manufacture of machinery for textile, apparel and leather production
5	2955	Manufacture of machinery for paper and paperboard production
58	2956	Manufacture of other special purpose machinery not elsewhere classified
10	2960	Manufacture of weapons and ammunition
60	3162	Manufacture of other electrical equipment not elsewhere classified
32	3220	Manufacture of telegraph and telephone apparatus and equipment; radio and electronic capital goods
57	3310	Manufacture of medical and surgical equipment and orthopaedic appliances
121	3320	Manufacture of electronic and non-electronic instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process control equipment
20	3330	Manufacture of electronic and non-electronic industrial process control equipment
19	3340	Manufacture of spectacles and unmounted lenses; optical precision instruments; photographic and cinematic equipment
31	3511	Building and repairing of ships
13	3520	Manufacture of railway and tramway locomotives and rolling stock
52	3530	Manufacture of aircraft and spacecraft
438	4521	General construction of buildings and civil engineering works
49	4523	Construction of highways, roads, airfields and sport facilities
1	4524	Construction of water projects
6	5114	Agents involved in the sale of machinery, industrial equipment, ships and aircraft
18	6321	Other supporting land transport activities
18	6322	Other supporting water transport activities
19	6323	Other supporting air transport activities
178	6420	Telecommunications
9	6521	Financial leasing
25	6523	Other financial intermediation not elsewhere classified (including investment and unit trusts)
6	6711	Administration of financial markets
34	67121	Fund management activities
23	7121	Renting of other land transport equipment
1	7122	Renting of water transport equipment
4	7131	Renting of agricultural machinery and equipment
94	7132	Renting of construction and civil engineering machinery and equipment
16	7210	Hardware consultancy (IT)
288	7222	Software consultancy and supply
207	7310	Research and experimental development on natural sciences and engineering
30	7320	Research and experimental development on social sciences and humanities

436	7420	Architectural and engineering activities and related technical consultancy
154	7430	Technical testing and analysis
2,552	**TOTAL**	

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