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Novel product innovation in project-based firms: explaining innovation where interdependent firms deliver complex system-level outcomes

Jerad Allen Ford

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ABSTRACT

Project-based firms (PBFs) are an increasingly important firm type in today's project-driven world. Over the next two decades, PBFs will transform nearly $60 trillion into complex product systems (CoPS) that comprise the communication, energy, and transportation infrastructure of our modern global economy. In the process, they will participate in a collective technological development process that is iterative, intensely inter-organisational, and dominated by their participation in large industry projects. In this environment, PBFs will deliver components, subsystems, and CoPS, some being novel products that are new to the world. These are called CoPS-related novel products.

However, the current understanding of how PBFs introduce CoPS-related novel products is lacking. In general, the existing innovation literature does not provide an adequate inter-organisational perspective, which is necessary to explain the development of new technologies by PBFs in CoPS settings. For instance, the new product development literature remains firm-centric and focused on manufacturing industries. The open innovation literature, although more focused on external relationships, is narrow is its consideration of the potential uses of open innovation, and is also focused on individual firm performance in manufacturing settings. Little is known about its role in networked settings like those in CoPS industries. The CoPS innovation literature itself remains too focused on the role of large system integrators, and not on the broader network of firms that support innovation. This leaves unscrutinised rest of the 'project-based productive network' of firms delivering products (components, technologies, and subsystems) into the higher-level CoPS. Taken together, the current literature inadequately addresses many factors that are important to novel product innovation in PBFs. Therefore, the central research question this thesis aims to answer is: *What factors facilitate PBFs' ability to introduce novel product innovations in environments where interdependent firms deliver complex system-level outcomes?*

Three specific challenges are imperative to understanding novel product introduction in PBFs. The first relates to the project-based nature of organising, which means that PBFs have contingent opportunities for novel product innovation, depending upon the circumstances of the projects they conduct. This is called the contingent opportunities problem. The second challenge is that PBFs have to ensure that their innovations are compatible with our technologies in their environment. This is called the technological interdependencies problem. The third challenge is that PBFs have enduring inter-organisational commitments that extend across the projects they conduct. This is called the enduring relationships problem.

Three research studies were designed and conducted to address the three specific challenges. The research is based on survey data collected from PBFs in the Australian upstream oil and gas industry. Study 1 investigates capabilities that PBFs use to overcome the contingent opportunities problems. This study finds that firms use an adaptive problem-solving capability to recognise opportunities within projects, and are reliant on networking capabilities to bring about novel product innovations. Study 2 investigates how PBFs use both inbound and outbound non-pecuniary open innovation practices to resolve technological interdependencies. This study finds that to introduce novel products, PBFs exhibit a narrow focus on their inbound knowledge flows. In the outbound, they reveal details to network partners about innovations. This is part of a stepwise process to gather feedback that is subsequently fed into R&D processes which, in turn, support novel product introductions. Study 3 investigates enduring relationships through a structural embeddedness lens focused on suppliers and customers. This study finds that supplier embeddedness supports novel products up to a point before it starts to detract, and that customer embeddedness only serves to diminish the positive influence of supplier embeddedness.

When the findings of these studies are synthesised, it reveals a new theoretical perspective on novel product innovation for PBFs in three themes. The first theme is that novel product innovations are most strongly supported by firm-level mechanisms operating at the intersection of projects, networks, and the PBF. This is because PBFs heavily leverage network partners in the development of innovations, they readily reveal details of innovations to network partners to improve them and ensure that they meet industry needs, and they narrowly search for innovation information—an indication of focus on the specific problem sets that the industry network partners/projects have currently identified. The second theme is that excessive commitment levels detract from novel product innovation. This is because excessive embeddedness may prevent PBFs from manoeuvring in novel ways, because they are so heavily embedded into reliable (incremental) technological role positions in the network. As part of this theme, searching broadly takes scarce resources away from solving current collective challenges, and represents a much less efficient approach to information gathering. The third theme is that information for novel product innovation is brought into the firm in a formal and structured manner. This is based on the import of moderate levels of supplier embeddedness and narrow search strategies. Together, these themes provide a compelling and nuanced answer to the central research question.

Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

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Publications during candidature

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Ford, J.A., Steen, J., & Verreynne, M.-L. 2014. How Environmental Regulations Affect Innovation in the Australian Oil and Gas Industry: Going beyond the Porter Hypothesis. ***Journal of Cleaner Production***, 81: 1-10 (cited 9 times as of 13 July 2015 - Google Scholar).

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Keywords

Project-based firms, novel product innovation, networks, open innovation, embeddedness

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EQUATIONS

ABBREVIATIONS

PBF(s)	Project-based firm(s)
CFA	Confirmatory factor analysis
CSG	Coal seam gas
CoPS	Complex product systems
NPD	New product development
LNG	Liquefied natural gas

CHAPTER 1: INTRODUCTION

Not all novel products are created equal. On one hand, consider the iPad—a well-known, mass-produced consumer product. The iPad upended the personal computing market and transformed the way we interact with the web. It represents the first mass-produced consumer tablet technology to be widely adopted by consumers. On the other hand, novel products that underpin the very fabric of our modern global economy are created and used in business-to-business contexts. These novel products are often highly specialised, and are thus produced in relatively low volumes for specific customers. Such products can be individual technological artefacts, components, or subsystems, as well as agglomerations of these things, known as complex product systems (CoPS). These CoPS-related novel product innovations are fundamental to the energy supply, communication and transportation infrastructure of the modern economy (Hobday, 1998). They allow you to charge your iPad, support your Skype calls on it, and send it—and you—hurtling through the air at 500 knots on your next international flight.

This thesis aims to describe the factors that support the firm-level introduction of CoPS-related novel product innovations. Novel means completely new to an industry. This is not an easy task because the introduction of such innovations is a highly interdependent and contextual process that involves not one single firm, but many firms engaged in collective efforts to support broader technological trajectories (Gann & Salter, 2000), contextualised by their participation in very large inter-organisational projects that regularly deliver CoPS, and arrays of inter-connected CoPS, such as those that underpin large oil and gas production systems (Ahola & Davies, 2012; Barlow, 2000; Gann & Salter, 2000; Miller & Lessard, 2000; Stinchcombe & Heimer, 1985).

The purpose of this chapter is to introduce the main aspects of this innovation narrative, to identify problems and gaps in the understanding of how these innovations are developed by firms, and to outline research studies that address the gaps. It has six sections. The first section describes what CoPS-related novel product innovations are, and the project-based firms (PBFs) that deliver them. The oil and gas sector is used as a backdrop for these sub-sections because it provides rich examples, and because it serves as a primer on the research setting of the thesis. The second section introduces the three problems that portend trouble for PBFs wishing to introduce novel product innovations in these settings: (1) **contingent opportunities** for innovation linked to the projects they conduct; (2) accounting for **technological interdependencies** between PBF innovations and the technology currently in use or being developed in the industry; and (3) **structural constraints** relating to the enduring nature of inter-organisational relationships that influence innovation activity. These challenges are introduced in this first chapter on a notional level, and detail is left for the literature review.

In the face of these specific challenges facing PBFs in the introduction of novel product innovations, the third section poses the central research question of this thesis: *What factors facilitate PBFs' ability to introduce novel product innovations in environments where interdependent firms deliver complex system-level outcomes?* This section also articulates the three research sub-questions, which each relate to three distinct challenges mentioned above. The fourth section introduces the individual research studies. Section 1.5.1 describes how capabilities enable firms to seize upon contingent opportunities and translate them into novel product innovations. Section 1.5.2 describes how open innovation helps explain how information is shared between firms to ensure that interdependencies in technologies are taken into account. Section 1.5.3 describes how structural embeddedness helps explicate the relationship between enduring relationships (particularly with suppliers and customers) and the introduction of novel product innovations. The last section introduces the research methods, and the sixth presents the structure of the rest of the manuscript.

1.1. What CoPS-related novel products are, and who develops them

This section introduces and describes novel product innovation created in CoPS settings, and the project-based firms (PBFs) that deliver them.

1.1.1. Novel product innovations

The energy sector is rife with examples of novel products, and the upstream oil and gas industry is an exemplar. This industry focuses on the exploration and production of petroleum resources. Over the last five years, there has been a substantial shift toward the extraction of oil and gas resources from very difficult geological formations, like coal beds (i.e. coal seams), shale, and other tight rock formations (collectively termed 'unconventional' resources) (The Economist, 2015). Until recently, these resources have been technologically infeasible to produce. But a confluence of several novel innovations has made locating and producing these oil and gas resources both technologically feasible and economical (Persaud, Kumar, & Kumar, 2003). So important are these technologies, that they are transforming the energy profile of the planet. By 2040, unconventional natural gas production will rise to two-thirds[1] of global natural gas output, up from one-fifth of output today (IEA, 2014a).

[1] 5,400 billion cubic meters per year

Several major technological advances have underpinned this shift. Advances in seismic imaging allow three-dimensional modelling and characterisation of gas basins, and four-dimensional modelling allows one to see changes in the reservoirs over time (JPT, 1998). These allow accurate location and characterisation of extremely thin geologic strata where the unconventional resources are trapped (Mohaghegh, 2013). Advances in computing allow engineers to determine gas flows through the rock formations, before any production wells are even drilled (Mohaghegh, 2013). Innovations in 'pad drilling' allow up to eight horizontal wells to radiate from one location to access these deposit[2]s (Speight, 2013). From these pads, geosteering technology facilitates highly accurate horizontal drilling, so accurate drillers can stay within a three-metre vertical interval for a 1,500 metres distance, at a depth of 4,500 metres (Saggaf, 2008; Speight, 2013). Horizontal drilling is often paired with hydraulic fracturing (together commonly called "fraccing"), which uses high pressure water to break open thin layers of semi-permeable rock, along with special surfactants, in order to induce gas to flow into the well (Golden & Wiseman, 2015; Persaud et al., 2003).

Based on these innovations—and a few more—a new industry segment is being born in Queensland, Australia. Currently, three large projects comprise a $60b international investment to develop coal seam gas into liquefied natural gas (CSG to LNG). This combination CSG and LNG technology is new to the world (Margolis & Hough, 2014). CSG to LNG will link together thousands of geographically distributed CSG wells to substations and pipelines that will clean and transport natural gas thousands of kilometres to facilities on the east coast where it will be compressed into LNG, placed on ships, and shipped to buyers in Asia (ABC, 2012).

The unique circumstances of CSG to LNG have spurred an additional wave of novel product innovations. For instance, CSG wells will produce billions of tonnes of salt water, and billions of dollars are being invested in novel technologies to recover salt and reuse the water in agricultural applications (Raine, 2012). Murphy Pipe and Civil (a civil engineering and construction firm) has developed a semi-continuous pipe-laying system to weld, inspect, and quickly bury tens of kilometres of pipeline at a time (Campbell, 2012). Their fast fusion system quickly welds sections of large diameter HDPE pipe, inspects it, and then promptly buries it using a specialised plough. Murphy developed the novel products that comprise this system by in-licensing fast-fusion technology from the US, and through collaborative research and development (R&D) with Foeckersperger—the German plough manufacturer that originally designed the equipment to bury small diameter telecommunications pipe. In their R&D efforts, Murphy made over 90 technical adaptations to successfully introduce this complete product system to the oil and gas industry (Campbell, 2012). As a result, pipe-laying throughput has increased dramatically, allowing upwards of 20 kilometres of pipe to be laid in a single shift.

Another example is drilling. Because CSG wells only produce gas for a handful of years, as compared to 30 years for a conventional gas well, new wells must be drilled and brought on line every year to meet the high volume of gas needed for the LNG production. Thus, much of the operational expenditure in this industry will actually be in the form of drilling projects. Firms in the CSG to LNG industry have thus pursued the goal of increasing the speed that wells can be drilled and completed, in order to decrease incremental costs. In this vein, Easternwell (an oil field services provider) created the Advantage® drilling rig that has reduced the time to drill and complete a CGS well by 80 per cent, down to three days from fourteen. To develop this novel product, Easternwell conducted collaborative R&D with an engineering design firm in Texas, and with their primary client Santos in Australia. The drastic time reductions were achieved by designing several new automated systems on the rigs, including safety systems and pipe handling, a first for the Australian oil and gas industry.

Novel product innovations of this type are considered complex product systems (CoPS) (Acha, Davies, Hobday, & Salter, 2004; Davies & Hobday, 2005; Gann & Salter, 2000; Geyer & Davies, 2000; Hobday, Davies, & Prencipe, 2005; Hobday, Rush, & Tidd, 2000; Nightingale, 2000). CoPS are defined as ‘high-cost, engineering-intensive products, systems, networks, and constructs’ (Hobday, 1998: 690). The use of ‘the term “complex” is used to reflect the number of customised components, the breadth of knowledge and skills required, and the degree of new knowledge involved in products, as well as other critical product dimensions’ (Hobday, 1998: 690).

CoPS are very complex and extend well beyond the capability of any one firm to create the components for them, which is why they are developed through inter-organisational collaborative projects (Hobday, 1998). The development of CoPS, and their component technologies, is based on a system of inter-organisational coordination which shapes the development of the individual technologies and systems used (Hobday, 1998; Miller & Lessard, 2000; Nightingale, 2000). These activities are contextual responses to the needs of major industry projects which provide firms both the opportunity and impetus for making innovation investments (Acha, Gann, & Salter, 2005; Barlow, 2000; Brady & Davies, 2004; Davies & Brady, 2000; Whitley, 2006). Visionary industry projects spur innovation because they often contain unparalleled scientific and engineering challenges (Kardes, Ozturk, Cavusgil, & Cavusgil, 2013; Miller & Lessard, 2000). For instance, public works projects, like stadiums or transportation hubs, often strive to be iconic and cutting-edge (Davies, Gann, & Douglas, 2009; Flyvbjerg, Bruzelius, & Rothengatter, 2003), and subsystems and systems used in the design of these CoPS are often first-of-a-kind applications of new technologies (Flyvbjerg et al., 2003; Priemus, van Wee, & Flyvbjerg, 2008). For example, the largest upstream oil and gas projects are more likely to be built around new core technologies (Merrow, 2011). This is why large complex projects are often called 'systemic innovations' (Miller & Lessard, 2000: 197) or collapsed innovation and diffusion projects (Hobday, 1998). They earn these monikers because these inter-organisational projects contain everything within them. This means that front-end design (which stipulates the end goal—often cutting-edge), the construction (necessary to realise that goal), and delivery to the customer (often another business, or a government) are all accomplished within a single inter-organisational project (Miller & Lessard, 2000).

In sum, CoPS-related novel products have been conceptually described components, and subsystems, related to the development of CoPS which are part of complex engineering and construction endeavours within an industry. A notional diagram of the nested-nature technology in CoPS settings is shown in Figure 1. It uses the CSG to LNG industry as an example. At the highest level, CSG to LNG is a 'system of systems' project that entails connecting many CoPS together to achieve a higher level function (Shenhar & Dvir, 1996). Below this are key CoPS that support the industry—including the drilling and pipe-laying examples mentioned before—and a few more, including water treatment, gas processing facilities, LNG plants, and LNG export terminals. Below this are key subsystems that support these CoPS and below that, the component technologies that support the subsystems. This diagram is indicative of the nested nature of technology and innovation that typify CoPS industries, and shows how these are connected to the conduct of visionary industry projects.

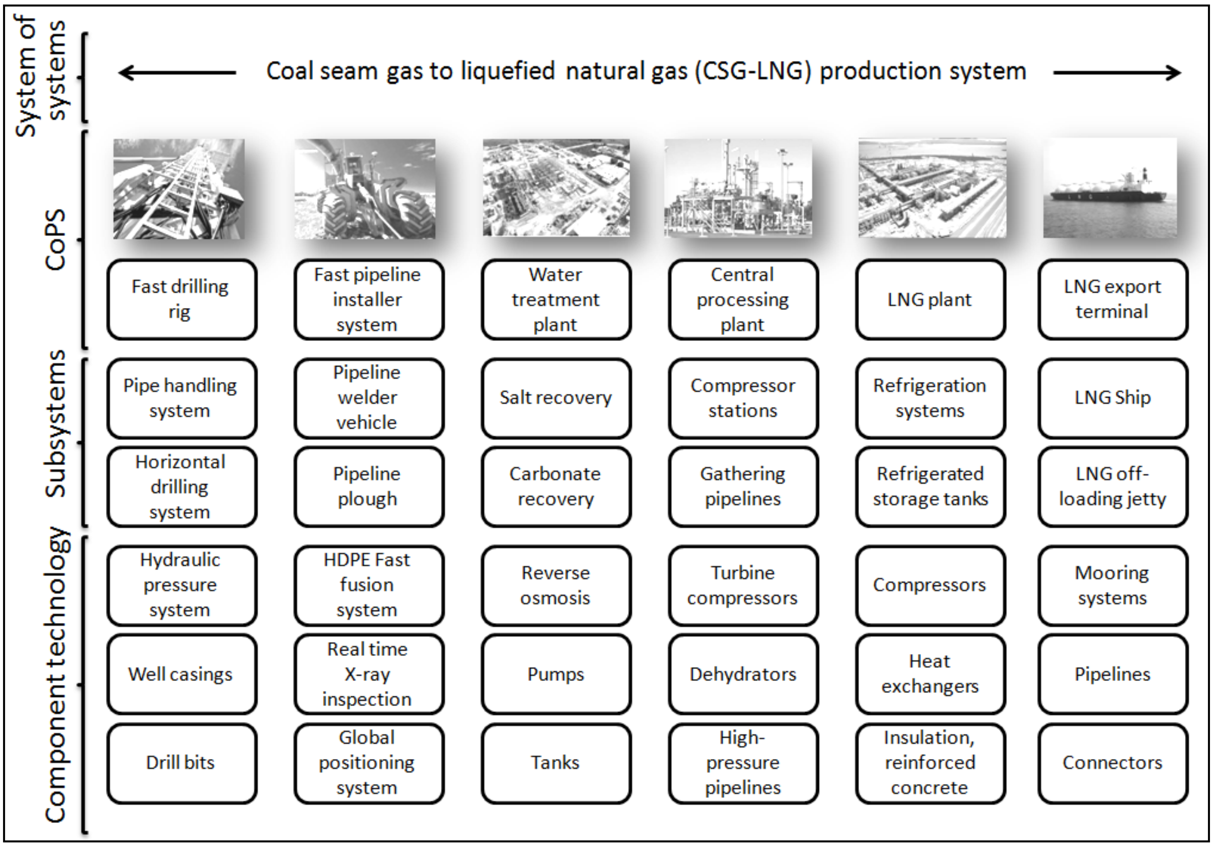

Figure 1 - Depiction of the nested nature of CoPS technologies and innovation

1.1.2. The role of project-based firms (PBFs)

The main actor considered responsible for innovation activities in CoPS settings are project-based firms (PBFs) (Gann & Salter, 2000; Hobday, 2000; Prencipe & Tell, 2001; Whitley, 2006). For these firms, projects dominate all business activities. Projects are used in the delivery of products and services to the industry, and the means by which innovation activities are pursued (Hobday, 2000). The project form of organising is the most appropriate organisational form to address the highly differentiated and customised requirements of clients, because projects confer the unique ability to recombine knowledge in new and novel ways to create innovations (Gann, Salter, & Dodgson, 2012). Examples of PBFs include consulting firms, design engineering firms, architectural firms, construction firms, and technology contractors that perform design, construction, assembly, and system integration roles (Gann & Salter, 2000).

But PBFs do not operate in isolation, and a network perspective is necessary to understand the nature of innovation in CoPS settings (Gann & Salter, 2000). In this vein, Gann and Salter (2000: 959) develop the term 'project-based productive networks' (Figure 2).

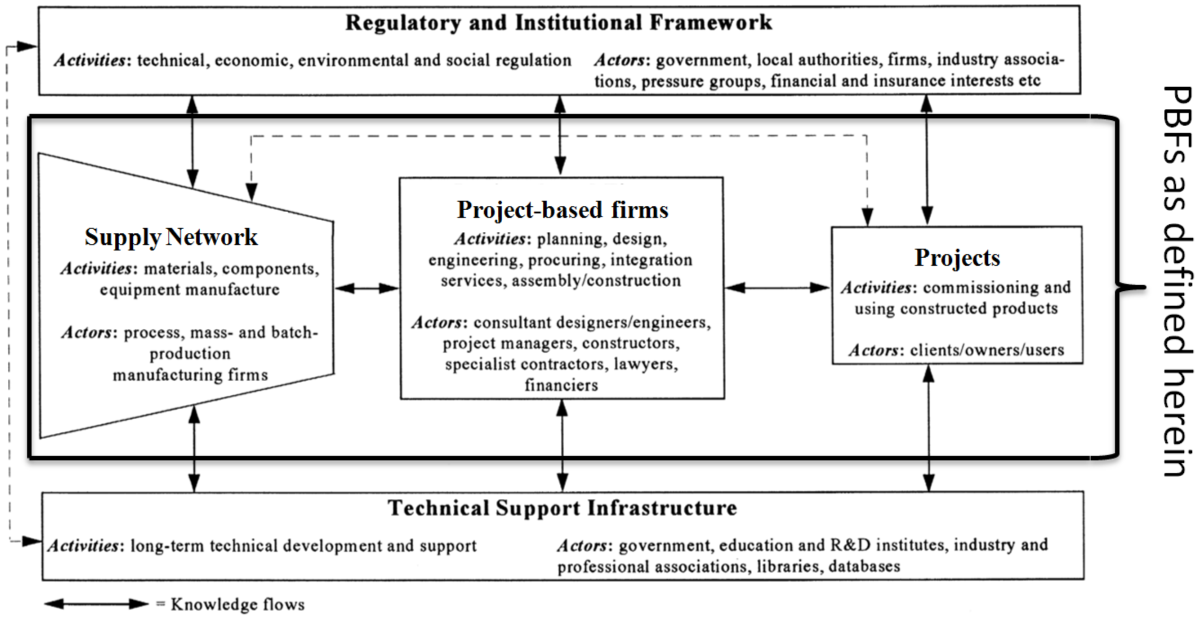

Figure 2 - Project-based productive network (adapted from Gann & Salter 2000)

Gann and Salter's (2000) conception of these networks identifies the main entities involved in technological progression and innovation activities of CoPS industries. The entities directly supporting industry projects are located in the middle layer of Figure 2. From right to left, these include: **projects** comprised of clients, owners and users; **PBFs** comprised of consultants, designers, engineering constructors, and contractors; and **supply networks** comprised of specialised manufacturers that deliver equipment, components and materials. The regulatory layer (top) represents external pressures on the innovation, and the technical support layer (bottom) provides longer-term technology support. The development of innovation in these project networks is a knowledge-intensive process requiring significant iterative technical exchanges between project owners, PBFs, and their supply networks, which is contextualised by the conduct of industry projects (Gann & Salter, 2000). To understand innovation, one must look at how these firms work as a collective. Participating firms must work hard to understand where their individual products and technologies fit into the technological trajectory of the industry (Gann & Salter, 2000) and into how innovation activities are supported and accepted by their immediate supplier and customer connections (Whitley, 2006). For these reasons, this thesis expands the prior definition of PBFs to include the cross-section of firms that represent the main production function of CoPS industries. Here, PBF is defined herein as 'a firm with primary business activities that are in support of the conduct of industry projects, including supplying products and services, conducting project tasks, or sponsoring industry projects'.

1.2. Problems facing PBFs

Organising by projects has direct implications upon novel innovation introductions at the firm level. There are three specific problems that influence innovation activities of PBFs. These problems must be overcome—or accounted for—to explain how PBFs introduce novel products into interdependent operating environments. First, the opportunities for innovation are contingent upon the projects in which the firms participate in or support. This means that PBFs that introduce novel products will be adept at recognising and capitalising on opportunities presented to them in the context of their projects. Second, innovations are interdependent in nature because they constitute subsystems and systems that are part of larger CoPS. This means that PBFs must accommodate other technologies in the development of their own, and must do so by engaging outside of their own boundaries. Third, PBFs are situated within enduring inter-organisational relationship structures common to all project-based industries. These structural characteristics may present both opportunities and potential pitfalls in PBFs' innovation efforts.

1.2.1. Contingent opportunities

CoPS-related novel products are almost always direct responses to industry needs that are encountered within industry projects (Acha et al., 2005; Gann & Salter, 2000; Gann, 2000). The opportunities for innovation present themselves in many ways—from the general industry trends, and the functional requirements of specific projects, to resolving unexpected circumstances that arise during design and execution. These are introduced here.

At the highest level, industry trends are a major impetus for innovation. Returning to our running example, the CSG to LNG projects posed several unique circumstances that provided the impetus for novel product innovations. The cost to drill thousands of CSG wells based on (what was) current technology translated into exorbitant costs. This led to the development of a new drilling rig with new-to-industry features that reduced the time to drill by 80 per cent. The problem of connecting thousands of geographically scattered wells with slow and tedious pipe-joining and burying processes provided the basis for the development of a semi-continuous welding, inspection, and ploughing system. Had these needs not been recognised by the developing firms as industry problems, they might never have been attempted.

Industry needs are also sometimes articulated very clearly in terms of the specific requirements of projects. For instance, a client can commission a visionary project that requires significant levels of innovation (Acha et al., 2005; Gann & Salter, 2000; Keegan &

Turner, 2002). One example is found in Barlow (2000) that details the BP Andrews field off-shore oil platform as the first to be completely designed and assembled on-shore, before being sent to sea. This required several design innovations, resulting in a completely new substructure design that saved millions in cost over earlier designs. Another example is a client requiring construction time to be cut by one-third to build a chemical plant, which demanded several innovations to accomplish (Keegan & Turner, 2002).

A major impetus for innovation resides in problems stemming from uncertainty within complex projects (Stinchcombe & Heimer, 1985). Large engineering projects are wrought with uncertainty and regularly experience unexpected events representing problems needing to be solved (Atkinson, Crawford, & Ward, 2006; Chapman & Ward, 2011; Stinchcombe & Heimer, 1985). Problems stem from a number of sources including: new technologies becoming available (Floricel & Miller, 2001; Jaffe & Palmer, 1997; Miller & Lessard, 2001); complex interactions between components and within sub-systems (Nightingale, 2000; Söderlund, 2002); environmental interfaces (Stinchcombe & Heimer, 1985); and even stakeholders pressure (Scott, Levitt, & Orr, 2011). In very complex projects, these uncertainties are never fully resolved until the project ends (Jaafari, 2001). Hence, unexpected events can occur at any stage of the project lifecycle. These problems often require very innovative responses to resolve them. For instance, in the offshore oil and gas industry, novel redesigns of offshore oil platforms have been required in the face of changing environmental conditions (Stinchcombe & Heimer, 1985). In CSG to LNG, the gas offloading jetty for one of the projects had to be completely redesigned when, in the middle of construction, assumptions about the subsurface geology made the original designs obsolete (Anonymous APLNG executive , personal communication, 2012).

Resolving these problems may represent opportunities to develop novel products, but this likely hinges on network coordination. This is because in most large projects, delivering a technological response is a cooperative effort involving firms that have collective responsibilities for systems and their interfaces (Barlow, 2000; Gil, Miozzo, & Massini, 2012; Stinchcombe & Heimer, 1985). Changes require engaging network partners in order to negotiate the technological response (Miller & Lessard, 2000). Integration of the novel product requires involving stakeholders, so that impacts to the rest of the project can be fully understood—including any impacts to the eventual operation of the asset (Gil et al., 2012). Hence, the ability to deliver a novel product technology also relies heavily on the ability to leverage and communicate the value of the novel product to the network of relationships that are affected by it (Gil et al., 2012). A major reason that change requires significant involvement of the network is the complicated and nested nature of the technologies in CoPS, requiring the integration of knowledge residing in disparate firms (Brusoni, Prencipe, & Pavitt, 2001).

In short, to understand how novel product innovations are introduced, one must understand how PBFs uncover opportunities and respond to problems presented by projects they participate within, and how they translate these into novel product innovation. This likely involves both a problem-solving ability, and the ability to leverage network connections.

1.2.2. Technological interdependencies

An important distinguishing feature of CoPS-related novel product innovations is their interdependent nature: They do not operate in isolation. Instead, technologies rely on each other and fit into a larger system of production (Gann & Salter, 1998, 2000; Gann, 2000). Using the running example of CSG to LNG innovations, technologies collectively support an industry set on the exploration for—and production of—difficult-to-produce natural gas deposits. Horizontal drilling technology would be of little consequence without the detailed 3D modelling that locates the gas deposits with great precision (Mohaghegh, 2013). Fraccing would not be as useful without the accompanying computing power to calculate the permeability and fracturing characteristics of the rocks, nor without the specialised surfactants that improve flow (Mohaghegh, 2013). Burying 17km of pipe in a day could not be accomplished if the lengths of pipes were not welded together at the same pace. Drilling 40,000 coal seam gas wells in 30 years (ABC, 2012) would not be economically feasible were it not for advanced high speed drilling rigs. Ergo, CSG to LNG projects would not be possible without all of these technologies fitting together; accommodating for each other, building off of each other, and complementing each other.

If innovations were developed without consideration of interdependencies, they would have trouble finding complicit suppliers or receptive users. As it is, however, successful innovations do find a broad base of support precisely because they fit into the larger technological trajectory of the industry, filling particular technological niches and addressing known collective problems (Gann & Salter, 2000; Gann, 2000).

One major reason that novel product innovations achieve fit is directly related to high levels of inter-organisational knowledge sharing (Acha, 2008; Gann & Salter, 2000; Manley, 2008). PBFs introducing innovative products go to great lengths to reduce the technological and market uncertainty surrounding an innovation, by investing time and resources in the coordination of the design, and coordinating specifics of production, of the novel products across the network of customers, suppliers, and even regulators (Acha, 2008). The projects that PBFs participate in most often serve as the backdrop for these knowledge flows (Gann & Salter, 2000; Manley, 2008). In complex construction projects, for instance, high levels of knowledge transfers occur at the front end of projects where modelling, simulation, and testing of designs require the integration of knowledge from complex supplier networks, each with distinct engineering and other specialist competencies (Gann & Salter, 2000). Of particular import in these knowledge exchanges are the resolution of interdependencies between the subsystems and components (Gann & Salter, 2000).

In short, any attempt to understand how PBFs develop novel product innovations must reveal the knowledge-sharing mechanisms by which interdependencies between technologies are accounted for—and integrated into—the development efforts.

1.2.3. Structural constraints

In the backdrop of project-based industries exist latent network structures (Cacciatori, Tamoschus, & Grabher, 2011; DeFillippi & Arthur, 1998; Grabher, 2004; Jones & Lichtenstein, 2008). What is meant by latent networks is that, although projects are finite endeavours, PBFs tend to maintain relationships with other firms that span across multiple projects. For example, firms tend to repeat collaborations across similar classes of projects; this is particularly true with large multi-national corporations who form stable cliques with their primary contractors (Davies & Hobday, 2005; Jones & Lichtenstein, 2008). For instance, energy giant Conoco-Philips and engineering firm Bechtel have maintained a global strategic alliance to develop LNG facilities around the world since the late 1960's, according to Bechtel and Energy News Premium (2015; 2002). Returning to a prior example, Easternwell developed the fast-drilling rig in conjunction with Australian oil and gas producer Santos, and regularly collaborates with Santos in this way.

To be sure, this does not mean that these relationships are exclusive. Returning to our example, Easternwell's goods and services are also used by several competing firms. The same is true for Murphy Pipe and Civil's pipe-laying innovations, which are being used by multiple firms in the marketplace. Bechtel, although having a formal alliance with Conoco-Philips (one of the project sponsors for the CSG to LNG projects in Australia), is also partnered with lead firms in two competing projects to build their LNG facilities. So instead of being exclusive, these embedded relationships tend to be pervasive, and duplicative.

Enduring relationships may have negative consequences toward innovation. On the one hand, in creative industries (e.g. television, film), enduring relationships are considered bedrock for innovation because they engender trust and understanding of each other's roles, which in turn allows for easier adaptation and improvisation (Bechky, 2006; Meyerson, Weick, Kramer, Kramer, & Tyler, 1996). On the other hand, being too closely tied to the same firms will serve to limit the flow of new knowledge that would support the development of novel innovations (Uzzi, 1997). This should be a particular concern for PBFs, where innovation is a highly interdependent process, and enduring relationships are a direct reflection of a stable roles and responsibilities vis-à-vis the supply of technology (Gann & Salter, 2000; Whitley, 2002, 2006). As firms become dependent upon one another for particular technologies, introducing novel product innovations becomes a difficult proposition. This is because novelty disrupts the stable technology trajectory of the industry, and in the process such firms may be labelled risky partners, which in turn promotes reputational damage (Whitley, 2002).

In short, to understand the introduction of novel product innovations by PBFs, one must also understand the effect of enduring relational structures, which in the case of PBFs in CoPS settings, may have particular downsides. Thus is important to understand what types of embeddedness are supportive of novel product innovation, and what types are not.

1.3. Research questions

The central concern of this thesis is to understand how PBFs overcome the challenges posed by project-based organising in order to introduce novel product innovations. A brief discussion on the choice of the firm as the level of analysis, and choice of novel product introduction (as an outcome), precedes the statement of the research question.

The focus on the firm is an effort to improve our understanding of PBFs, which are an increasingly important firm type across a range of sectors (Gann et al., 2012). This firm type is crucial to the delivery of energy, communication and transportation infrastructure around the globe (Hobday, 1998), areas which are seeing a veritable explosion of billion-dollar-plus projects (Economist, 2005; Flyvbjerg, 2014). An estimated $57 trillion dollars will be invested globally in communication, transportation and energy infrastructure projects by 2030 (Kardes et al., 2013; McKinsey, 2013). Of this, an estimated $40 trillion will be spent on energy supply infrastructure (IEA, 2014b), and $22 trillion of this is estimated to be oil and gas megaprojects (Ernst & Young, 2014).

Even though PBFs are heavily influenced by industry projects, they do in fact remain individual firms. The challenge is to understand, for this class of firms, what allows them to introduce novel products in such an environment? What patterns exist across PBFs that `provide insight into how the barriers of project-based organising are overcome to introduce novel product innovations? A focus on the firm progresses our understanding of how firms deal with a shroud of external context, and still introduce novel products.

The focus on the *introduction of*, and not *performance of*, novel products is because of the contingent and interdependent nature of innovation. PBFs play specific technological roles in tandem with others, and this comprises a network of interlinked technology providers that defines the technological and innovation trajectory of the entire industry. PBFs must not only be able to recognise opportunities in the first place (contingent opportunities problem), but ensure their innovation fits in the industrial technological trajectory (interdependent technologies problem), and ensure fit with desires expressed by technologically-reliant network partners (enduring relationships problem). Hence, the outcome of interest is not innovation performance of PBFs because the problem is not to understand how PBFs compete against each other. The problem is to understand how PBFs fit into, and enhance, the technological progression of the broader industry by helping to solve collective problems that industry (and its projects) face (Gann & Salter, 2000). Therefore, the focus on the *introduction* of novel product innovations more explicitly targets the phenomenon of interest.

Having established the need to focus on the firm (PBFs), and the introduction of novel products as the outcome, the central research question can be stated as: *What factors facilitate PBFs' ability to introduce novel product innovations in environments where interdependent firms deliver complex system-level outcomes?*

This central research question leads to three specific sub-questions, each related to the three aforementioned challenges that PBFs face in their efforts to develop novel product innovations: (1) contingent opportunities defined by projects in which they participate; (2) interdependencies with other technologies being produced by other firms; and (3) enduring relationship structures between PBFs, particularly their customers and suppliers. Each of these challenges speaks to the contextual and inter-organisational nature of innovation for PBFs. The three research sub-questions are:

(1) What factors help explain how contingent opportunities are capitalised upon to introduce novel products?

(2) What factors help explain how technological interdependence is accounted for in the introduction of novel product innovations?

(3) What is the impact of enduring inter-organisational relationships on the introduction of novel product innovations?

1.4. Addressing the research questions

This section derives an approach to addressing the central research question and each of the sub-questions. This is done by following three paths of inquiry that directly match the three distinct challenges that PBFs face: (1) **Capabilities** to address **contingent opportunities**; (2) **Open innovation** to understand how **technological interdependency** is resolved; (3) **Structural embeddedness** as a means to explicate the association between **relational constraints** and novel product innovation. Table 1 summarises these relationships in terms of the individual studies. The logic behind this approach is provided in the following subsections.

Table 1 - Summary of studies

Central Question: What factors facilitate PBFs' ability to introduce novel product innovations in environments where interdependent firms deliver complex system-level outcomes?

	Specific PBF problem	Sub-question	Lens / study name	Reasoning and approach
1	Contingent opportunities	What factors help explain how contingent opportunities are capitalised upon to introduce novel products?	Capabilities	• Capabilities have long tried to explain novel product innovation propensity of firms (Collis, 1994; Teece, Pisano, Shuen, & Wiley, 1997). • In slower-paced environments firms may rely first-order capabilities (Hine, Parker, Pregelj, & Verreynne, 2013; Winter, 2003). • PBFs regularly engage in problem solving and networking as a regular mode of doing business (Davies & Hobday, 2005; Stinchcombe & Heimer, 1985).
2	Technological inter-dependence	What factors help explain how technological interdependence is accounted for in the introduction of novel product innovations?	Open innovation	• Purposeful knowledge flows across firm boundaries are of known import in novel product development (Chesbrough, 2003). • Non-pecuniary forms are likely important in PBF settings, particularly search (Laursen & Salter, 2006) and revealing (Henkel, Schöberl, & Alexy, 2013).
3	Relational constraints	What is the impact of enduring inter-organisational relationships on the introduction of novel product innovations?	Structural embedded-ness	• Embeddedness assumed positive for PBFs (Davies & Hobday, 2005; Jones & Lichtenstein, 2008). • Social capital literature warns of ill-effects from over-embeddedness (Uzzi, 1997). • PBFs involved in projects with thousands of firms (Davies et al., 2009). • Existing approaches require direct measure (Rowley, Behrens, & Krackhardt, 2000). • New approach is needed.

1.4.1. Study 1: Capabilities

That firm-level capabilities are largely responsible for the serial development of new products is not a new concept (Collis, 1994; Leonard-barton, 1992; Teece et al., 1997). For instance, dynamic capabilities is one particularly compelling theory about how firms modify and extend existing resources (e.g., people and equipment) into new business areas and new products, and in so doing achieve performance advantages over competitors (Eisenhardt & Martin, 2000; Teece et al., 1997; Winter, 2003). Dynamic capabilities are particularly well-suited to explain how firms in high-velocity industries innovate (Zahra, Sapienza, & Davidsson, 2006). High-velocity markets are fast-paced consumer goods sectors like pharmaceuticals and computing, where technological change is rapid, the market dynamics are continuously changing, and, therefore, competitive advantage is often short-lived (Eisenhardt & Martin, 2000; Hine et al., 2013; Teece et al., 1997).

The PBF literature on capabilities related to new product development largely centres on how CoPS are developed by large firms, and an important vein focuses on system integration capability (Brusoni et al., 2001; Davies & Hobday, 2005; Geyer & Davies, 2000; Hobday et al., 2005). System integration capability is argued to be necessary for the modern corporation because the development of new (complex) products rests on the integration of disparate technologies and functional know-how spread across a diverse set of network partners (Davies & Hobday, 2005). As such, this capability mirrors that of the dynamic capabilities literature, in that it focuses on the recombination of resources, and in this case it extends beyond firm boundaries.

Yet, neither capability perspective sheds much light on how PBFs recognise and capitalise on the contingent opportunities they come across in projects, and how they leverage these opportunities into novel product innovations. It is argued that two capabilities, *adaptive problem-solving* and *networking*, are missing from the current discussion.

First, the need for adaptive problem solving in projects is well-known, and stems from the tremendous amount of uncertainty that firms face in large, complex engineering projects (Stinchcombe & Heimer, 1985). These projects are subject to high levels of dynamic change because they have protracted timeframes and many interacting parts (from component technologies, firms, and environment, to weather and stakeholders) that may lead to unanticipated events (Ahola & Davies, 2012; Stinchcombe & Heimer, 1985). These events are the sources of problems that are frequently mitigated by product innovations (Barlow, 2000; Davies et al., 2009; Nightingale, Brady, Baden-fuller, Hopkins, & Brady, 2011; Stinchcombe & Heimer, 1985). For instance, changes in environmental circumstances may dictate the novel redesign of a subsea structure for an oil platform in the middle of a project (Stinchcombe & Heimer, 1985). Or consider that a new technology that signifies significant cost savings comes to light years after initial design for an energy plant was drawn up. These instances are constantly occurring in large projects and require adaptation to handle. Despite this common knowledge, most of our understanding of responding to uncertainty is tied to the specific circumstances of projects (particularly the structure of project governance, and contract structures) and not viewed as a firm-level capability (Barlow, 2000; Davies et al., 2009; Floricel & Miller, 2001; Stinchcombe & Heimer, 1985).

A second capability is networking. Because PBFs operate regularly in inter-organisational projects, the ability to introduce novel products requires both the coordination with—and buy-in of—network partners (Gann & Salter, 2000; Taylor & Levitt, 2007). Despite this, the study of networking vis-à-vis CoPS innovation is only studied in the largest of PBFs—the multi-national firms that manage very large projects (Brady & Davies, 2004; Cattani, Ferriani, Frederiksen, & Täube, 2011; Davies & Hobday, 2005). As a consequence, we still know little about how networking is used by the numerous sub-tier firms responsible for innovation in such settings (Gann & Salter, 2000). In the largest projects, thousands of PBFs participate (Davies et al., 2009). It would seem that the ability to draw from and leverage network connections in the development of novel products would not be exclusive to only the top tier firms, but would be a capability that all (novel product innovating) firms would rely upon.

Two notions from the strategy literature help classify these missing capability perspectives. They are *ad hoc* problem solving and ordinary capabilities (Winter, 2003). First, according to Winter (2003) *ad hoc* problem solving is a non-routine response to unexpected circumstances. While non-routine activities are often viewed as higher order, and therefore dynamic, capabilities (Hine et al., 2013) *ad hoc* problem solving is not a dynamic capability in this setting since it is essentially an unpatterned organisational response not tied to any enduring higher-level organisational routine (Winter, 2003). This notion of *ad hoc* problem solving seems particularly well-suited to explain how PBFs resolve the uncertainty associated with CoPS projects and deliver innovative responses to problems that arise (Stinchcombe & Heimer, 1985). Thus a capability that is termed *adaptive problem solving* is developed herein.

Second, ordinary capabilities are those that support the normal mode of business for the firm (Winter, 2003). Ordinary capabilities are particularly relevant for PBFs because of the slow and incremental pace of technological that typify many CoPS industries (Barlow, 2000; Gann, 2000; Noke, Perrons, & Hughes, 2008; Whitley, 2006). In these low-velocity settings, firms have rarer opportunities for innovation than in high-velocity settings, and so maintaining a high-level dynamic capability (for new product development, for instance) that would be used rarely would be a waste of resources (Winter, 2003). In addition, dynamic capabilities are specific investments tied to particular outcomes, and are thus limited in their applicability to unknown or adverse problem sets (Hine et al., 2013; Winter, 2003). For PBFs, ordinary capabilities relate to the conduct of inter-organisational projects and delivery-interdependent technologies and systems (Hobday, 1998, 2000). In particular, networking seems to be a requirement for PBFs seeking to be successfully involved in the development of innovations inside project-based productive networks (Gann & Salter, 2000). Thus, networking capability is developed herein as the most important ordinary capability for PBFs.

PBFs are most likely to rely on a combination of *ad hoc* problem solving and ordinary capabilities to develop innovation, because this represents the most economic approach to innovation in low-velocity settings (Winter, 2003). As an *ad hoc* approach, adaptive problem solving will work in conjunction with PBFs' ordinary networking capabilities, to enable firms to deliver novel product innovations. Table 2 summarises the research question, problems approach, and contributions.

Table 2 - Study One impetus and contribution

Study One	What factors help explain how contingent opportunities are capitalised upon to introduce novel products?	
Capabilities	Basis	• Capabilities are often tied to the production of novel products. • Capability literature focused on dynamic capabilities in high velocity environments settings (Hine et al., 2013; Winter, 2003). • PBF capability literature is focused on system integrators (Hobday et al., 2005).
	Problem	• Current capability literature does not focus on adaptive problem solving or networking beyond the top level.
	Approach	• Dynamic capabilities not particularly relevant in low-velocity settings (Hine et al., 2013; Winter, 2003) which typifies many project-based industries (Whitley, 2006). Ordinary capabilities likely more prominent for PBFs. • PBF ordinary capabilities would relate to participation in inter-organisational projects and contributing to system level outcomes. Two important capability constructs based on the project literature, called adaptive problem solving and networking, are derived.
	Contribution	• Findings show that networking and adaptive capabilities are important to novel product innovation. Moreover, these capabilities do not operate alone. Problem solving operates through networking capabilities to support novel product innovations.

1.4.2. Study 2: Open innovation

Firms have increasingly opened up their innovation processes to external parties in an effort to incorporate new ideas and to cultivate commercialisation pathways (West, Salter, Vanhaverbeke, & Chesbrough, 2014). Chesbrough (2003) was the first to bring open innovation into the popular consciousness, through his observations of the increasing use of patenting and licensing in large high-tech firms in the Silicon Valley of California (Chesbrough, 2003; West et al., 2014). Since then, open innovation has garnered much academic attention as scholars have attempted to expand and extend the theoretical bases for it (Chesbrough, Vanhaverbeke, & West, 2006; Dahlander & Gann, 2010; West & Bogers, 2013). Today, the phenomenon is thought to be quite pervasive across industries, beyond high-tech industries, also present in mature industry settings like manufacturing, chemicals, and aerospace (Chesbrough & Crowther, 2006; Chiaroni, Chiesa, & Frattini, 2011; Laursen & Salter, 2006; Sjödin & Eriksson, 2010). Open innovation can be defined “as a distributed innovation processes based on the purposively managed knowledge flows across organisational boundaries, using pecuniary and non-pecuniary mechanisms in line with the organisations business model” (West et al., 2014: 806).This latest definition reflects recent work by Dahlander and Gann (2010), who argued that there are important knowledge flows moving across firm boundaries that do not entail direct financial transactions (i.e. are non-pecuniary).

Non-pecuniary knowledge flows are argued to be vital to PBFs’ innovation activities because of the network-like structure of project-based industries, and the way that these structures facilitate tacit knowledge flows (Gann & Salter, 1998, 2000; Jones, Hesterly, & Borgatti, 1997; Jones & Lichtenstein, 2008).Networks are structured patterns of inter-firm relationships supporting the development of new products and services, by inducing tacit knowledge flows facilitating assembly of diverse and complicated knowledge sets into new, novel combinations (Jones et al., 1997; Jones & Lichtenstein, 2008; Powell, 1990).Gann and Salter (2000) argue that network-like behaviour pervades the innovation activities of PBFs, and that inter-organisational relationships regarding innovation are never purely ‘buy-sell’ transactions (Gann & Salter, 2000). These network-like behaviours are a reflection of the highly tacit nature of knowledge that supports innovation in CoPS settings. They specifically demonstrate the argument that Gann and Salter (2000) make, which is that ‘know-how’, and ‘know-who’ are knowledge dimensions that are rarely codified, but that tend to remain tacit due to the bespoke nature of innovation in CoPS settings (Gann & Salter, 2000).

PBFs demonstrate this network-like behaviour in a number of ways. There is a high prevalence of formal collaborative relationships, exemplified by the prevalence of alliances between multi-national firms in complex construction and engineering settings (Jones & Lichtenstein, 2008). PBFs tend to maintain redundant ties with the same types of firms, so that specialist goods and services are accessible at a time when they are needed, because demand for services is hard to predict (Eccles, 1981; Jones & Lichtenstein, 2008). PBFs regularly engage in joint-engineering efforts to develop designs, something that is required since no single firm has the capabilities or resources to address all aspects of the complex designs that characterise CoPS-related innovations (Gann & Salter, 2000). Increasingly, PBFs provide blended product and service contracts to their customers, which means they provide integration, operation, and maintenance support alongside their subsystems and CoPS (Davies, Brady, & Hobday, 2007; Gann & Salter, 2000). For instance, Roll-Royce has moved to a service contract strategy where profit is made from providing 'power by the hour'. Customers do not buy a jet engine and parts to maintain it. Rather, customers buy a service that supplies engines alongside trained service and maintenance technicians to integrate and maintain the engine (Hobday et al., 2005). PBFs also regularly pool their intellectual property as a strategy to win the favour of their customers by providing innovative bids for complex construction project contracts (Davies, Brady, Prencipe, & Hobday, 2011).

Because tacit knowledge flows are very prevalent for PBFs, it follows naturally that technological interdependencies in the innovations they develop are likely to be resolved through tacit knowledge exchanges. The open innovation offers a lens to view these purposeful—but non-transactional—exchanges, referring to them as non-pecuniary knowledge flows (Dahlander & Gann, 2010). However, this matter has not been addressed in the literature, and there are two specific problems. First, the study of open innovation is almost non-existent in the study of PBFs. In one rare exception, Acha (2008) uses data from PBFs in the UK CoPS industries to relate their design practices to the degree of openness they exhibit, finding a strong positive relationship between PBFs' design practices and the use of open innovation, which indicates that indeed, open innovation plays a role in resolving technological interdependencies. However, this remains an exception, and leading scholars still remark that there remains a large gap in our understanding of open innovation in networked environments (Vanhaverbeke, 2006; West et al., 2014) in which, of course, PBFs operate (Gann & Salter, 2000). Yet, literature still continues to focus on manufacturing industries (e.g. Laursen & Salter, 2014, 2006).

A second problem is with the open innovation literature, which has excessive focus on inbound knowledge flows while ignoring increasingly important outbound open innovation flows (West & Bogers, 2013). Even the rare example of PBF open innovation reflects this bias toward inbound knowledge flows (Acha, 2008). That literature which has focused on outbound knowledge flows has focused on how revealing intellectual property can speed up product development efforts in fast-paced, high-technology settings like software and biotech (Henkel & Maurer, 2009; Henkel et al., 2013). These studies do not help to understand how PBFs might use outbound knowledge flows as a potential means to resolve interdependencies in CoPS settings.

Thus, the use of open innovation by PBFs is ripe for investigation. This study focuses on non-pecuniary knowledge flows, which fit well with the tacit nature of innovation knowledge flows for PBFs (Gann & Salter, 2000). Specifically, two flows are targeted: inbound non-pecuniary *sourcing* and outbound, non-pecuniary *revealing* (Dahlander & Gann, 2010). According to Dahlander and Gann (2010), *sourcing* is information obtained from the environment without a direct financial transaction. An example of sourcing is when firms search broadly for information across several existing knowledge channels (customers, suppliers, competitors, trade groups, etc.) to support the development of novel innovations (Laursen & Salter, 2006). Dahlander and Gann (2010) discuss *revealing* as the sharing of intellectual property or detailed technological information without an immediate prospect of a financial return. An example of revealing is the sharing of a preliminary design with customers to accelerate the innovation development process to create a new product innovation (Henkel et al., 2013). Using an open innovation lens and non-pecuniary knowledge flows will not only provide insights into the problem of technological interdependence for PBFs, but will also provide insight into open innovation use in networked environments in general, and CoPS settings in particular. A summary of the problem, literature, approach, and contribution are shown in Table 3.

Table 3 - Study Two impetus and contribution

Study Two	What factors help explain how technological interdependence is accounted for in the introduction of novel product innovations.	
Open innovation	Current state	• Open innovation (Chesbrough, 2003) is considered a critical perspective in explaining interorganisational knowledge flows to support novel product innovation (Chesbrough & Bogers, 2014; Chesbrough & Crowther, 2006; West & Bogers, 2013). • Non-pecuniary activities (Dahlander & Gann, 2010) should play a special role for PBFs because their networked nature of production and innovation (Gann & Salter, 2000; Jones et al., 1997).
	Problem	• Currently, resolution of technological interdependencies via openness has not garnered much attention outside of high-technology realms (Henkel et al., 2013), and open innovation has not been applied in general to network settings (West & Bogers, 2013).
	Approach	• This thesis adopts Dahlander and Gann's (2010) framework to hypothesise around inbound and outbound non-pecuniary open innovation strategies (sourcing and revealing, respectively). • It operationalises sourcing based on the problemistic search literature (Greve, 2003; Laursen & Salter, 2006; March, 1991, 1963) particularly search breadth (Laursen & Salter, 2006); Revealing is based on the notion of selective revealing of technological details to aid in the development and diffusion of innovations (Henkel & Maurer, 2009; Henkel et al., 2013).
	Contribution	• This study finds that selective revealing plays an important role in the introduction of novel product innovation, actually operating through (being mediated by) the firms R&D activities. This means that revealing solicits feedback and is an input to R&D activities and this ensures compatibility with other technologies. • Contrary to much of the strategy literature narrow (not broad) search plays a role in the introduction of novel products for PBFs.

1.4.3. Study 3: Structural embeddedness

Although projects are, by definition, temporary endeavours (Lundin & Soderholm, 1995), they are underpinned by enduring inter-organisational relationships operating in the background (Grabher, 2002a; Manning & Sydow, 2011; Sydow & Staber, 2002; Whitley, 2006). Embeddedness is the term often used to describe such relationships (Granovetter, 1985; Jones & Lichtenstein, 2008). Embeddedness is a key theoretical perspective that helps explains how PBFs coordinate action in a number of inter-organisational project domains (Jones & Lichtenstein, 2008).

Embeddedness is thought to have many advantages for innovation. Repetition of collaborations between firms over time, and across different projects, builds trust and increases mutual understanding of each other's business practices (Jones & Lichtenstein, 2008). By promoting this shared understanding of each others' role structures, embeddedness can help project team members to anticipate, recognise and respond to unexpected circumstances and to improve project outcomes and facilitate innovative improvisational responses (Bechky & Okhuysen, 2011; Bechky, 2006; Jones & Lichtenstein, 2008). This would be a boon for PBFs operating in complex projects wrought with unexpected events, allowing firms to quickly coordinate innovative responses (Stinchcombe & Heimer, 1985). Embeddedness also facilitates the communication of fine-grained tacit information relative to innovation (Uzzi, 1997). For example, system integrator firms depend on enduring relationships between key partners and several specialist component suppliers that are repeatedly drawn upon in different combinations to support innovation activities in CoPS industries (Cacciatori et al., 2011; Hobday et al., 2005; Hobday, 2000).

However, there are three problems in our understanding of embeddedness with regard to novel product innovation in PBFs. First, much of the literature is focused on system integrator firms. This severely limits the understanding of the multitude of firms at lower tiers of the industry that support innovation activities. Second, embeddedness may be responsible for innovation, but there are potential downsides because it suppresses access to new information (Uzzi, 1997). Being overly connected to close partners, including suppliers and customers in particular (Whitley, 2002), will tend to put pressure toward incremental innovation improvements closely tied to existing product offerings. In this light, embeddedness may cause PBFs difficulty in their attempts to introduce novel product innovations. Third, although the social capital literature defines embeddedness (Rowley et al., 2000), this has not been translated to the project literature. Moreover, with the large scale of industry networks supporting CoPS (Davies et al., 2009; Kardes et al., 2013), using the exacting measures from social capital literature would require direct observation of thousands of firm ties. Thus a proxy measure to operationalise embeddedness is needed.

This study places specific focus on firms' structural embeddedness with customers and suppliers because these linkages are suspected of having specific effects on novelty (Whitley, 2002). This is because the (limited) project literature appears to acquiesce to (rather than critically investigate) the importance of the customer in the innovation process (Blindenbach-Driessen and Van Den Ende, 2010; Manley, 2008), and largely ignores the important role that suppliers provide (Martinsuo & Ahola, 2010). Taking this one step further, there has been no apparent study of the effects of simultaneous customer and supplier embeddedness, specifically the impact of one on the other. Thus a moderating hypothesis is tested to see if customer embeddedness suppresses the effect of supplier embeddedness upon the introduction of novel product innovations. To accomplish this task, a proxy measure is developed that focuses on firms' formal collaboration patterns. This approach is drawn from the economic geography literature and the concept of geographic embeddedness (Song, Asakawa, & Chu, 2011). A summary of the research question, its basis, and the approach to addressing it is found in Table 4.

Table 4 - Study Three impetus and contribution

Study Three	What is the impact of enduring inter-organisational relationships on the introduction of novel product innovations?	
Structural embeddedness	Current state	• Literature points to the positive role that enduring relationships play in inter-organisational coordination and innovation (Gann & Salter, 2000; Jones & Lichtenstein, 2008).
	Problems	• Potential downsides to innovation related to overembeddedness (Uzzi, 1997). • Structural embeddedness (that which exists between firms) is not well-defined for PBFs. • Measuring requires direct observation of the entire network (Rowley et al., 2000).
	Approach	• Derive a proxy approach to measure structural embeddedness of PBFs. • Drawing from the economic geography and innovation literature (Song et al., 2011), based this on formal collaboration patterns of project-based firms, specifically suppliers and customers. • Test relationship between these two types embeddedness (and over embeddedness) using innovation survey data from project-based firms in one particular industry • Test the impact of customer embeddedness upon supplier embeddedness (interaction effect) (Whitley, 2002).
	Contribution	• Methodological contribution is identified that measures structural embeddedness by proxy in a statistically representative cross section of a project network, useful for very large networks that cannot be directly observed. • Interaction of embeddedness: high embeddedness with customers adversely impacts the positive contribution of benefit of supplier embeddedness. • Ill effects of embeddedness: over-embeddedness with suppliers may detract from the likelihood of novel product innovation.

1.5. Research methods

To facilitate this research, a quantitative survey method was used. A well-regarded innovation survey instrument, developed by The Cambridge University Center for Business

Research (CBR), was used for this purpose (Cosh, Fu, & Hughes, 2012; Cosh, Hughes, Bullock, & Milner, 2009; Cosh & Hughes, 2000, 2003).The instrument garners firm-level information, including performance, collaboration, and innovation activities. It includes standard definitions of innovation (type and degree of novelty), which follow international guidelines for defining and measuring innovations outlined by the Organisation for Economic Co-operation and Development's (OECD) Oslo manual (OECD, 2005). These guidelines have helped to standardise data collected at the national level. For instance, Europe's Community Innovation Surveys (CIS) follow these guidelines and continues to spawn a great deal of high quality research focused on understanding the determinants of innovation and performance outcomes (Collinson & Wang, 2012; de Faria, Lima, & Santos, 2010; Freel, 2004; Grimpe & Sofka, 2009; Kostopoulos, Papalexandris, Papachroni, & Ioannou, 2011; Laursen & Salter, 2006, 2014; Reichstein, Salter, & Gann, 2008; Schmiedeberg, 2008; Sofka & Grimpe, 2010; Spithoven, Vanhaverbeke, & Roijakkers, 2012; Tether, 2002).

The use of an existing survey on innovation that follows the same OECD standard definitions and guidelines offers the benefits of comparability with prior studies and high interpretability of the results. This is an important point, since much of the literature on projects and project-based firms is qualitative in nature, and not well-linked to the innovation literature that has these very standard and robust measures for innovation and collaboration—that can be compared to other studies from other sectors—which would allow for meaningful cross-industry and firm type comparisons. Building on this strong base of standard measures, the Cambridge instrument was augmented in minor ways to accommodate the oil and gas industry context (see section Chapter 3). These augmentations were made through a rigorous and iterative process that involved consultation with the following: oil and gas experts in the consulting firm Ernst and Young, industry executives, and the premier trade group in Australia for upstream oil and gas—the Australian Petroleum Production and Exploration Association (APPEA).

This instrument was then used to survey executives in a cross-section of PBFs that contribute most directly to the conduct of industry projects, and most directly to the innovations used there (Gann & Salter, 2000). PBFs are defined here as: firms with primary business activities that are in support of the conduct of industry projects, including supplying products and services, conducting project tasks, or owning industry projects.

The PBFs that were sampled come from the upstream oil and gas industry of Australia. Upstream oil and gas refers to the exploration and production of petroleum resources. Exploration includes the search for oil or gas resources, and production involves all the steps necessary to extract resources (Persaud et al., 2003). This includes construction of significant amounts of infrastructure, technology, and tooling to produce these resources. This setting was chosen for two reasons—fit and opportunity. First, upstream oil and gas is a project-based industry that is mature in age (Acha & Cusmano, 2005; Crabtree, Bower, & Keogh, 1997; Stinchcombe & Heimer, 1985) and has a project-productive network that mirrors that described in Gann and Salter (2000). The industry age, and limited customer sets, means that the PBFs in this industry tend to maintain relatively stable technological niches in the production network (Whitley, 2006), and thus this industry is a good candidate to obtain a cross-sectional representation of PBFs. Second, the Australian upstream oil and gas industry is currently undergoing an unprecedented $350b investment in nearly a dozen multi-billion dollar projects which affects nearly every firm in the industry (BCA, 2012; Reuters, 2013). Thus, the firms operating in the research setting are influenced heavily by these significant projects during the period of study. This context further justifies the selection of the research setting as one very appropriate to answer the research question.

The intent behind obtaining a cross-section of these firms is that the actual project-based productive network is comprised of hundreds, if not thousands, of firms (Davies et al., 2009), making it hard to observe an entire network directly. To aid in the identification of this representative sample of PBFs from this network, APPEA provided access to their executive membership list, which they claim represents 98 per cent of the production capacity of the of the Australian oil and gas industry. Their membership and includes nearly one hundred oil and gas operators, and nearly 300 contractors and suppliers. This list was culled by the author to keep only those firms technologically linked to the industry projects. For instance, pure service firms like law firms were removed, as well as ancillary support agencies and universities. Data were gathered using computer automated telephone interviewing (CATI) technology in two periods in 2013 and in 2014. In total, 173 individual firms comprise the sample used herein.

A variety of statistical approaches, including logistic regression, were used to assess the relationships between firm-level attributes and the introduction of novel products. These attributes include capabilities, open innovation practices, and structural embeddedness with customers and suppliers. This approach allows first the identification of the firm-level characteristics that relate to novel products, and second, higher-level inferences about the patterns of inter-organisational activities for PBFs that are important to introducing novel product innovations in interdependent, project-based settings.

1.6. Document structure

This document is divided into eight chapters. Chapter 1—this Introduction—provided a high level perspective on the impetus for the research and structure of the research studies. Chapter 2 is the literature review that more fully develops the research sub-questions for each study. It stops short of hypothesising, which is accomplished within each of the individual study chapters (5, 6, and 7). Chapters 3 and 4 cover the research methods in two parts. Chapter 3 contains information on the theoretical perspectives adopted (ontological and epistemological), particulars of the research setting, the survey method, the sample, and the statistical techniques used. Chapter 4 contains the variable construction and construct development, specifies the models, and displays the tests of robustness for the data. Chapters 5, 6, and 7 are the individual studies: Chapter 5 focuses on structural embeddedness (Study 1); Chapter 6 on open innovation (Study 2); and Chapter 7 on capabilities (Study 3). Each study is presented in three parts: hypotheses, model testing, and a discussion. Chapter 8 summarises and concludes the thesis.

CHAPTER 2: LITERATURE REVIEW

This literature review introduces the specific impetus for the central research question and its sub-questions, and the literature that is drawn upon to resolve them. This chapter does not include hypotheses, which can be found in the first section of each of the individual studies, presented in Chapters 5, 6 and 7.

This literature review is structured into four sections. The first section establishes the conceptual background for the research. It discusses innovation theory and what it says about novel products. It then discusses the unique nature of CoPS-related innovation, in order to clearly delineate the differences between this, business-to-business, nested, inter-organisational and project-based, form of product innovation that differs in many ways from much of the extant discussion on new products based upon mass-produced consumer goods. This section also clearly defines the outcome variable of interest, which is the 'CoPS-related novel product'. The second section discusses the gaps and research questions. It first analyses the landscape of what we currently know about CoPs-related novel products. It identifies the high-level gaps in both the CoPS literature and the innovation literature, mainly highlighting lack of attention paid to the inter-organisational activities of PBFs that are responsible for innovation. Then specific gaps are detailed, relating to the problems first introduced in the introduction (continent opportunities, interdependent technologies and enduring relationships). The third section details the path forward to addressing these challenges by providing more detail from the literature: Capabilities to address contingent opportunities, open innovation to resolve technological interdependence, and structural embeddedness to understand the effect of enduring relationship on CoPs-related novel product innovations. A fourth section summarises the chapter.

2.1. Conceptual background

This subsection briefly discusses the relevant innovation theory and more fully describes the unique nature of CoPS-related novel products, their definition, and measurement.

2.1.1. Innovation theory and novel products

Much of the current-day thinking on innovation derives from the seminal work of Schumpeter (1934), who is recognised as one of the first to establish the importance of different types of innovation as the primary source of economic change. Schumpeter identified five different types of innovation: new products, new methods of production, new sources of supply, new market exploitation, and new organisation of the business. Important to this is the distinction he made between goods (products) and means of production (processes). In Schumpeter's view, the economy is underpinned by the interplay between products and processes in particular, characterised by firms operating along a long vertical chain, where one firm's goods become another firm's production inputs. This chain of events continues until the ultimate end user is reached. In this view, the creation of new goods in the economy results from the actions of entrepreneurial firms that create novel combinations of product inputs, transforming them into unique production processes, and consequently producing new products for subsequent customers. Put simply, lower order goods are always combinations of higher order goods. These ideas of Schumpeter have formed the basis of a large part of the research that makes up the field of innovation studies (Becheikh, Landry, & Amara, 2006; Bhupatiraju, Nomaler, Triulzi, & Verspagen, 2012; Fagerberg, 2006; Martin, 2012).

Schumpeter's five types of innovation remain relevant today. They are embodied in the current iteration of international standards for measuring innovation set by the Organisation for Economic Development and Cooperation (OECD). The Oslo Manual (OECD, 2005) defines four types of innovation: product (includes physical products and service products), process, marketing and business. These definitions form the basis of many national-level innovation surveys conducted in the developed world, including Europe's Community Innovation Surveys (CIS), Australia's national innovation surveys (Bloch, 2007), and surveys of British businesses conducted by the Centre for Business Research (CBR) at Cambridge University (Cosh et al., 2012, 2009; Cosh & Hughes, 2000, 2007, 2009). Table 5 maps the relationships between Schumpeter's five types of innovation, the Oslo Manual's four types and definitions, and the CBR's six types of innovation. The CBR instrument is the basis for the current research and treated in more detail in Chapter 4, *Methods Part II*.

Table 5 - Relationships between innovation types

Schumpeter (1934) types	OECD (2005) types	OECD (2005) standard definition	CBR types‡
1. New products	1.Product innovation	'the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses. This includes significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics' (p. 48).	1. Product innovation 2. Service Innovation
2. New methods of production 3. New sources of supply	2.Process innovation	'the implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software' (p. 49).	3. Process innovation 4. Product delivery innovation 5. Service delivery innovation
4. New market exploitation	3. Marketing innovation	'the implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing' (p. 49).	6. Managerial innovation
5. New organisation of business	4. Organisational innovation	'the implementation of a new organisational method in the firm's business practices, workplace organisation or external relations' (p. 59).	

‡ (Cosh et al., 2012, 2009; Cosh & Hughes, 2000, 2007, 2009)

As the leading guide for measuring innovation, the Oslo manual also urges differentiation between innovations that are only new to the firm and those that are completely new to the market or to the world (OECD, 2005). This differentiation is referred to as the degree of novelty (Fagerberg et al., 2006). Incremental innovations lack in novelty, and are likely to be improvements upon existing products and product lines. More radical or novel innovations represent completely new technological categories (Dunlap-Hinkler, Kotabe, & Mudambi, 2010; Freel, 2003; Garcia & Calantone, 2002; Grimpe & Sofka, 2009; Laursen & Salter, 2006; Reichstein & Salter, 2006). These novel innovations are completely new and may embody new machinery, or a cluster of closely related innovations that work together and have far-reaching impact (Fagerberg, Mowery, & Nelson, 2006).

The ability of firms to introduce novel products remains of utmost concern in the strategy literature because it strongly relates to firm performance and enduring competitive advantage (Köhler, Sofka, & Grimpe, 2012; Laursen & Salter, 2006; Praest Knudsen & Bøtker Mortensen, 2011; Wagner, 2010; Yannopoulos, Auh, & Menguc, 2012). Novel innovations are sometimes also called radical or architectural innovations, because they are tumultuous in nature, and stretch to the limits the current innovation-related competencies of firms that is closely tied to existing product lines (Gatignon, Tushman, Smith, & Anderson, 2002; Henderson & Clark, 1990; Leonard-barton, 1992). This means that novel product innovations are inherently hard work, and difficult to serially produce. But benefits may accrue to those firms that can produce them. Firms that are adept at developing novel products are those that stay ahead of the competition, get first mover advantages, and may accrue the most reward for their innovative effort (Fagerberg, 2006). In this tradition, authors have studied everything from antecedents of novel products (Freel, 2003; Lane, Koka, & Pathak, 2006; Ritala & Hurmelinna-Laukkanen, 2013) to specific performance outcomes (Duysters & Lokshin, 2011; Laursen & Salter, 2006, 2014). For instance, the antecedent ability of the firm to recognise the value of external information useful to its internal innovation activities is noted to be a key element of innovation capacity (Cohen & Levinthal, 1990; Lane et al., 2006). Also, performance outcomes like the percentage of new products comprising firm revenues are used to understand how firms' information seeking behaviours relate to innovation outcomes (Laursen & Salter, 2006).

2.1.2. Unique nature of complex product systems (CoPS) innovation

While traditional innovation studies have helped to progress an understanding of novel product innovation, this literature focuses on mass-produced products, manufacturing settings, and individual firm performance (Becheikh et al., 2006). As such, it does not adequately describe the nature of CoPS-related novel products, which are more bespoke, nested and inter-organisational (Hobday, 1998). There are three distinct points of difference between CoPS innovations and mass-produced goods innovations. First, CoPS are created in business-to-business contexts and are tailored to the specifications of a limited set of buyers who are often large multi-national firms or governments (Hobday, 1998). Thus, CoPS have relatively well-defined markets for innovation (Hobday, 1998), whereas mass-produced goods require the creation of new markets (O'Connor & Rice, 2013; Rogers, 1995). Second, CoPS have bespoke product architectures required by their unique combinations of components and sub-systems, a requirement of the tailored nature of design for specific customer users (Davies & Frederiksen, 2010; Hobday et al., 2005; Hobday, 1998). Thus, CoPS are nested products with tailored interfaces (Hobday et al., 2005) in contrast to discrete products with modular interfaces that typify many consumer goods like computers (Ethiraj, 2007). Third, CoPS are built by integrating diverse knowledge sets inside inter-organisational projects (Barlow, 2000; Davies & Frederiksen, 2010; Davies et al., 2009; Hobday, 1998).

This is a requirement due to the highly complex nature of the innovations, and the need to combine differentiated knowledge that resides in many disparate specialist firms (Brusoni et al., 2001). CoPS therefore result from project-based production methods instead of high-volume manufacturing processes (Davies & Frederiksen, 2010). Table 6 summarises these differences and more, and the next sections expand on these three points.

Table 6 - Differences between CoPS and mass-produced consumer goods

	Complex product systems	Traditional commodity products
Product characteristics	• Complex component interfaces • High unit cost	• Simple interfaces, modular designs, • Low cost
Production characteristics	• Project/small batch	• Continuous/large batch
Innovation processes	• User- and producer-driven • Innovation and diffusion collapsed into one and agreed upon by suppliers and users	• Supplier driven • Innovation and diffusion separated and mediate by market preference
Competitive strategies and innovation coordination	• Systems integration competence • Management of multi-firm alliances in temporary projects	• Volume production competency • Focus on single firm and lean production
Industrial coordination and evolution	• Elaborate inter-organisational networks • Temporary multi-firm alliances for innovation and production • Long-term stability at system integrator level	• Large firms/ supply chains • Single firm as mass producers • Alliances for R&D or asset exchange • Dominant designs
Market characteristics	• Large transactions • Business to business • Negotiated prices	• Many smaller transactions • Business to Customer • Market prices

Adapted from Hobday (1998)

CoPS have well-defined markets

In the innovation literature, a major concern is the diffusion of the product across a market interface, which is the integration of individual consumer adoptions. This process is characterised as convincing an unwilling market to adapt to the change embodied in the new product. Product diffusion increases over time as more and more consumers adopt it, and this follows an "S" curve (first slowly and then, at a certain point, expanding rapidly). Everett Rogers identified this trend in a seminal study of agricultural seed products in his 1995 book *Diffusion of Innovations.* Rogers argued that the adoption of products by a given market is governed by five main categories of socially-related factors. These include: (1) The perceived attributes of the innovations (including the relative advantage of the new product over the existing, the compatibility with other products and processes the use user maintains, the perceived complexity of integrating the technology into the user's operations, the ability to trail the technology before obligating, and the ability to observe the performance of the product in its proposed function); (2) The type of innovation decision (e.g. optional, collective effort among many co-dependent partners, regulatory fiat); (3) The communications channels that are used to promote the innovation (e.g. media, interpersonal discussions); (4) The nature of the social system the users are in, including its norms and how interconnected the network is); and (5) The extent of the promotion efforts by the change agent.

A particularly important point of distinction between mass-produced products and CoPS is the collapsed nature of innovation and diffusion. CoPS are reflections of bespoke requirements of a limited market. Diffusion does not occur across a market interface *per se*, it occurs within the confines of the CoPS development project(s) and the customers commissioning it who are usually large multi-national corporations or governments. These customers often represent the whole market for new CoPS. The market with the components and subsystems are defined by this CoPS development. Thus, CoPs-related novel products do not diffuse per se, but are introduced by negotiating iteratively with existing customers and network partners, who integrate novel products into their products and systems at appropriate times within the context of the industry projects (Gil et al., 2012; Taylor, Levitt, & Fellow, 2006). This does not serve to make the diffusion of novel product innovation easy; it is just negotiated inter-organisationally (Miller & Lessard, 2000). If the product affects many commonly used systems (common to many firms in the network, and where the interfaces between systems matter), a coordinated effort to diffuse the technology is necessary (Taylor et al., 2006). Products affecting common systems mean that interdependent firms would have to adopt the innovation at the same time. Uneven adoption means that an adopting firm may be out of synch with others in the network, posing problems in project execution. For instance, the US building construction industry was slow to adopt 3-D design software because of these interdependencies (Taylor et al., 2006).

CoPS are nested, interdependent technological systems

Examples of CoPS include state-of-the-art airport terminals, commuter highways, bridges and tunnels, high-speed railways, hydroelectric dams, petrochemical plants, commercial and military aircraft, wireless and satellite telecommunication networks, nuclear power plants, missile defence systems, water treatment and supply infrastructure, off-shore oil production platforms, and LNG plants (Davies & Frederiksen, 2010; Flyvbjerg et al., 2003; Hobday, 1998; Van Marrewijk, Clegg, Pitsis, & Veenswijk, 2008).

CoPS, however, are not just stand-alone products—they are actually sophisticated agglomerations of many components and sub-systems (Hobday et al., 2005). These components and sub-systems are not standardised modular components as one finds in industries like computer manufacturing (Ethiraj, 2007) or bicycle components (Fixson & Park, 2008). Instead they are often unique, built to individual specifications (Hobday, 1998). Where modularity *is* achieved in CoPS subsystems, the decomposability of the design does not have a commensurate effect on organisational knowledge. In other words, the customer firm must understand the outsourced design nearly completely, in order to ensure that they can aggregate artefacts into components, components into subsystems, or subsystems into CoPS (Prencipe, 1998). This makes the introduction of components, subsystems, and CoPS a very interdependent process.

An example helps describe this nested nature of CoPS. As Figure 1 showed (*see* Chapter 1), there are a number of CoPS, subsystems, and components that support the Australian CSG to LNG industry. This industry is currently being created in Australia via the conduct of approximately $60b worth of projects aimed at developing the infrastructure—technologies that will enable the future supply of liquefied natural gas produced from coal seams to Asian markets. CSG to LNG is a ‘system of systems’ project because it integrates several CoPS together into a higher level function (Shenhar and Dvir, 1996). In this case, CoPS interact in a process that extracts, transports, cleans, processes and ships LNG. This effort consists of several major CoPS including drilling rigs, pipe-laying systems, water treatment plants, central processing plants, LNG plants, and LNG export terminals. These high-level CoPS are each comprised of several sub-systems and component technologies. Drilling rigs consist of a number of subsystems like horizontal drilling technology, automated pipe-handling systems, and other drilling-related computer systems that in tandem comprise the ‘fast’ drilling rig technology (Easternwell, 2015). Below these subsystems, component technologies include drill bits and hydraulic pressure lines, for example. Pipelines are buried using CoPS consisting of a pipeline welder and plough subsystems, comprised of components including x-ray inspection and GPS, among others (Campbell, 2012). Water treatment plants consist of salt recovery and carbonate recovery subsystems that rely on reverse osmosis component technology (Sherriff, 2012). Central processing plants clean and pressurise the raw gas for subsequent transport, hence they have major subsystems consisting of gathering lines and compressor stations, and components including turbine compressors and dehydrators (APNLG, 2012). The LNG plant further compresses this gas using refrigeration and compression technologies, and stores the gas in insulated, reinforced concrete tanks. The export of gas is facilitated by a jetty connecting the tanks to the LNG ships, and includes components ranging from ship mooring systems to connectors facilitating the safe transfer of gas from the terminal to the ship (APNLG, 2012).

CoPS are developed inter-organisationally by project-based firms

Complicating our understanding of how novel products are introduced is that innovation is not in the domain of a single firm, but in a collection of entities called project-based firms (PBFs). PBFs play important innovation roles within the inter-organisational projects that produce CoPS (Hobday, 1998; Miller & Lessard, 2000). The introduction of product innovations by PBFs is an inter-organisational process, shaped by iterative technical exchanges between project owners, project firms, and their supply networks in the conduct of projects (Gann & Salter, 2000). Gann and Salter (2000) conceptualise these inter-organisational relationships and knowledge flows that support innovation as ‘project-based productive networks’ (p. 959) (refer to Figure 2, Chapter 1). These project networks explain how work is accomplished and how innovation is developed in many project-based industries like infrastructure, building construction, aerospace, and upstream oil and gas.

The entities that form the middle layer of the diagram are called PBFs and are defined herein as ‘firms with primary business activities that are in support of the conduct of industry projects including supplying products and services, conducting project tasks, or sponsoring industry projects’. These firms are most directly responsible for the conduct of industry projects and the innovations produced within them (Gann & Salter, 2000).

In terms of innovation, it is necessary to consider these firms as one group, and an example helps explain how these PBFs inter-relate vis-à-vis innovation. Upstream oil and gas industry projects are commissioned by owners like Shell, Chevron, and Exxon-Mobil. Their projects are aimed at the developing new oil and gas resources. Projects they commission involve the development of sophisticated engineering infrastructure, equipment, and systems that the owner will eventually use to produce oil and/or gas resources in the ensuing years. These projects include everything from design and construction of wells and pipelines to processing plants and storage tanks, and all the component technologies and CoPS therein, as has been described as being the case in the CSG to LNG industry. As project owners, these firms set the tone for innovation by setting functional specifications for components, subsystems, and their related CoPS; by introducing design challenges tied to the particular project; and at the same time bringing their own innovations and technologies into the projects (Barlow, 2000; Bower, Crabtree, & Keogh, 1997; Crabtree et al., 1997). For instance, consider the $52b Gorgon natural gas development project in Western Australia. This project is being built on Barrow Island, a Class A nature reserve, which spurred efforts to create both the modular infrastructure to reduce its environmental footprint, as well as the world's largest quarantine system to decontaminate all staff and equipment allowed onto the island. The entire LNG production facility was modularised to limit impacts on the nature reserve, and a world-class quarantine management system was created to decontaminate thousands of personnel and millions of tonnes of materiel (UNAA, 2012). The project also includes one of the world's largest carbon dioxide sequestration projects (Cook, 2009). An estimated $15b-$20b will be over the life of the project spent to sequester 125 million tonnes of carbon dioxide (Cook, 2009). Firms like Chevron rely heavily on engineering design firms, they help refine the project vision including system architectures, and they pursue design innovations based on their desires (Acha et al., 2005; Keegan & Turner, 2002). Other project firms like oil field services providers conduct sub-projects around drilling and pipeline construction, and bring CoPS systems, technologies, and products to bear around these areas (Bower et al., 1997). These firms in turn rely on a supply network of specialist material and services providers. They deal in highly specialised technologies including pipes, engines, gauges, pumps, turbines, and tailored technical services like seismic imaging and inspection (Bower et al., 1997). The ability to introduce innovation into this interconnected system requires significant coordination across the network. For instance, if a lower level specialist provider wants to integrate a novel pump technology, this may trigger an engineering design review of the complex product it goes into, and also requires project owner approval to use novel technology in the production setting (Bower et al., 1997). In many cases, the customer will be directly involved in these primary innovation activities, since they are critical to the performance of the asset and to the profitability of the client (Hobday, 2000).

2.1.3. Defining and measuring CoPS-related novel products

Definition

The nested relationships between components and subsystems mean that there are myriad potential loci for product innovations within project networks developing CoPS. Each technological artefact, component, sub-system, or CoPS brought into being represents a viable locus for the development of a new product that is new to both the industry and market (OECD, 2005). This thesis considers this nested nature in developing a working definition of

‘CoPS-related novel products’. A CoPS-related novel product is defined as an artefact, component, sub-system, complex product system (CoPS), or combination thereof that constitutes a technologically new—or significantly improved—physical product / technology, that is both new to the firm and new to the industry. This definition fits the spirit of product innovation as defined by the innovation management literature, and also captures the degree of novelty by stating that the innovation is not only new to the firm but also new to the industry to which it was introduced (Fagerberg, 2006; OECD, 2005).

Measurement

This thesis focuses on how CoPS-related novel products are introduced, rather than their performance, for three reasons. First, the introduction of a CoPS-related novel product is an empirical instantiation of a technology that was commercialised to address a collective industry problem (Gann & Salter, 2000). The process to develop such innovations is shaped by inter-organisational factors that are related to the project-based nature of organising and inter-organisational innovation processes that enable CoPS. It is a highly iterative and contextual process. Measuring the introduction of an innovation captures the pure essence of a commercialisation in a highly interdependent technological setting. It does so more clearly than would a performance metric such as the percent of sales from new products. Introduction of an innovation clearly means that it has been implemented (OECD, 2005). Performance may help differentiate competitive success, but that is not a concern here for PBFs in CoPS project networks. PBFs must orient innovation activities outward in order to be successful innovators at all, and success in this setting means plugging into the industry technological trajectory, and playing an enduring role in the innovation system (Gann & Salter, 2000). Competitive differentiation is less a concern than the way firms collectively introduce a CoPS-related novel product innovation.

A second reason to focus on the introduction of novel products is that performance measures may obfuscate simple relationships that are important to improving the understanding of phenomena in exploratory studies. For instance, in one of the first highly regarded empirical studies on technological search, Katilia and Ahuja (2002) tested the relationship between two new operationalisations of search breadth and depth (based on patent citation patterns) and new product development in US robotics firms. Rather than attempt to tie their new operationalisations of search breadth and depth to performance measures like sales, Katilia and Ahuja (2002) related them to the simple count of new products introduced. In another more recent example, the relationship between rarely studied knowledge accumulation patterns of firms and the introduction of novel innovations was investigated (Kelley, Ali, & Zahra, 2013). In a similar way, this thesis study breaks some new ground in attempting to apply quantitative rigor to a largely qualitative corpus of work on innovation in PBFs, where the definitions of innovation are not consistently applied, and several assumptions regarding lead firms' directorial role in the innovation process remain untested (e.g. Brusoni, 2005; Davies and Brady, 2000; Hobday et al., 2005). This study uses a well-honed definition of CoPS-related novel product innovation, and looks for the simple introduction of such innovations, in order to most clearly explicate the fundamental relationships between them and the inter-organisational factors most likely responsible.

A third reason for not focusing on performance data is practical nature of measuring sales in a CoPS setting. Sales from innovations for a PBF are not as clear-cut as would be sales from a manufacturing firm producing a new mass-produced product. In upstream oil and gas for example, innovations often have near-term costs and delayed or indirect revenue streams. Recall the discussion about fast drilling rigs in the CSG to LNG industry (see section 1.1.1). Easternwell developed this innovation to meet industry demands to speed up the process of drilling. This innovation represents a direct cost to the firm. Revenues associated with this innovation will derive from future oil field services contracts over the next 20 years to conduct drilling operations for clients. Another example is an oil and gas operator investing in technological innovations and infrastructure that will ultimately support the production of petroleum products in the long-term. An innovation that increases the efficiency of processing oil and gas would represent a direct cost that is offset by indirect cost savings garnered from future operations. Neither of these examples show revenues tied directly to the sale of a novel product. Such revenues are the well-regarded performance measures used in innovation studies (e.g. Laursen & Salter, 2006). Thus, innovation performance data of the type typically associated with manufacturing firms is not relevant for PBFs.

2.2. Gaps and research questions

This section reviews the general and specific gaps in the understanding of CoPS-related novel product innovation. The first subsection discusses the three general gaps that provide the impetus for this thesis. First, the mainstream innovation literature on new product development (NPD) has not pivoted toward the bespoke, interdependent, and inter-organisational development process that characterise CoPS. Instead it remains consumer goods-focused and firm-centric (Becheikh et al., 2006; Cooper, 1982; Evanschitzky, Eisend, Calantone, & Jiang, 2012). Therefore the insights derived from it are limited in their application to settings where inter-organisational collaboration is a choice, rather than a fundamental aspect of doing business as it is for PBFs. Second the innovation literature best situated to increase our understanding of CoPS-related novel products—the open innovation literature—does not do a good job of understanding the bi-directional flow of knowledge (in- and out-bound) nor explores open innovation in networked environments (Vanhaverbeke, 2006; West et al., 2014). Third, the CoPS innovation literature itself is limited. It either focuses on the roles of system integrators—the top-level firms that deliver CoPS—or it narrowly focuses on the particular context of particular projects. In both cases, the production network of PBFs responsible for the development of innovations is not directly studied. These general gaps give rise to the central research question: *What factors facilitate PBFs' ability to introduce novel product innovations in environments where interdependent firms deliver complex system-level outcomes?*

The second subsection discusses three specific gaps in the current understanding of innovation PBFs that give rise to the research sub-questions and related studies. As previewed in the introduction, three specific problems that PBFs face in their endeavours to introduce novel product innovations are: (1) contingent opportunities, (2) the need to resolve technological interdependencies, and (3) the effects of enduring relationships.

2.2.1. General gaps

Product innovation literature limitations

The innovation literature most directly focused on new product development (NPD) shows preferences toward the characteristics of single autonomous firms and individual product attributes, in terms of how each relate to marketplace performance (e.g. revenues, market capture) (Cooper, 1982; Evanschitzky et al., 2012). Of course, this focus is not without warrant; most new product innovation efforts by firms are not successful. Estimates of new products failing to garner the projected market they had planned to reach range anywhere from 50 to 90 per cent (Cooper, 1982; Evanschitzky et al., 2012). Even industrial firms, more likely to focus on business-to-business transactions and therefore with better-defined markets, still fail with new product introductions 40 per cent of the time (Cooper, 1982). Consequently, much attention has been placed on success factors within the control of the focal firm. For example, Evanschitzky et al. (2012) looked at 233 studies from 1999-2011 in their meta-analysis of factors affecting new product success. Although they included some external market dynamics and competitive factors, there were very few externally focused factors like collaboration with external parties. Out of more than 30 variables sampled, only three represent externally oriented factors that might directly and positively influence new product success. These included ‘product meets customer needs’ (the extent to which product is perceived as satisfying desires/needs of the customer) and ‘customer input’ (whether the firm incorporated customer specifications into new product initiatives)—neither of which achieved significance in the meta-analysis. The third factor, ‘external relations’ (coordination and cooperation between firms and other organisations), did positively relate to new product success (moderate effect size of .2, n=24,756) (Evanschitzky et al., 2012).

Another meta-analysis by Becheikh et al. (2006) focused on the determinants of product and process innovations. This study reveals a similar bias toward internal firm factors and manufacturing firms. Out of 208 studies selected for investigation, 37 variables comprise the internal determinants of innovation; ten variables were assessed as contextual determinants. Of the latter, just two focused on purposeful interaction between external parties. They were networking with other parties including, for example, research institutes and customers, and formal knowledge/technology acquisition activities, both having rather mixed relationships to performance (no meta-statistics were provided direction or size of relationships).

In terms of markets, NPD literature still reflects the notion that novel products are foisted upon potential users in an effort to create a market. In a recent award-wining paper[3] on the subject, O’Connor and Rice (2013) argue that producing novel innovations (they term these ‘breakthrough innovations’, which are substantively new and offer significant benefits over prior products) requires a substantial and commensurate investment in creation of the market. They argue that the market for new product innovations is created through the interactions between focal firms and potential customers, and with other firms that comprise the emerging value chain for the mass-produced product.

Open innovation literature limitations

NPD literature aside, there has been a shift in the innovation literature toward external relationships best embodied in the literature on open innovation (Chesbrough & Crowther, 2006; Chesbrough et al., 2006; Laursen & Salter, 2006; West & Bogers, 2013). Open innovation is the focus on knowledge flows across firm boundaries to enhance and expand the opportunities for innovation (Chesbrough, 2003). Although open innovation continues to garner considerable interest in the literature (West et al., 2014), our understanding of it

[33] Paper of the year 2013, Journal of Product Innovation Management

relative to PBFs remains limited in two ways. First, there is an excess of concern about inbound forms of open innovation (West & Bogers, 2013). This focus assumes that knowledge is brought into the firm for the purposes of creating new innovations and improving performance. There has been very little research on outbound forms of open innovation, which is how firms create and extend markets for innovation (Chesbrough, 2003). There has been even less research on inbound and outbound forms of open innovation at the same time, which would help explicate their relative importance to innovation outcomes and how they work in tandem (Gassmann & Enkel, 2004). One of the few attempts is Laursen and Salter (2014) who established that inbound search was linked to the number of appropriability strategies (including patenting, and secrecy) that manufacturing firms' tended to use. However, only some appropriability strategies are related to open innovation, for instance secrecy is not one (Cohen, Nelson, & Walsh, 2000). Meanwhile other important outbound forms remain understudied empirically, including how firms use selective revealing of innovation and facilitate co-creation activities with customer sand partner and spur interest from potential customers (Henkel et al., 2013). This latter aspect of open innovation seems particularly relevant to PBFs, because innovation is deeply reliant on cross-boundary knowledge flows that do occur in purely buy-sell exchanges between firms (Gann & Salter, 2000).

A second limitation concerns the understanding of open innovation in networked environments (Vanhaverbeke, 2006; West et al., 2014). In networked environments, firms have lasting inter-organisational relationships that directly impact on innovation processes, potentially serving as inbound sources of information, and as pathways for commercialization (West & Bogers, 2013). Inter-organizational networks are important in creating innovations in high-tech industries like biotech (Fabrizio, 2009; Powell, Koput, & Smith-Doerr, 1996) and to capture value from them (Vanhaverbeke, 2006). However, less attention has been paid to firms operating in settings where inter-organizational collaboration is more frequent, such as those involved in the design and delivery of innovative CoPS (Hopkins, Tidd, Nightingale, & Miller, 2011). In this setting, the interdependencies in the delivery of complex capital products mean that firms are considered to be highly networked (Gann & Salter, 2000). Here, firms' innovation activities are largely defined by cross-boundary knowledge flows (Gann & Salter, 2000). Furthermore, this literature implicitly discusses firm open innovation in the context of how firms fit into a larger (inter-organizational) innovation network and how individual success hinges on the ability to conform to, and anticipate the, technology trajectories in the industry (Gann & Salter, 2000; Gann, 2000; Whitley, 2006).

CoPS literature limitations

The literature that is specifically focused on CoPS is limited itself in two ways. First, a gap results from lack of attention on the inter-organisational nature of innovation that characterises CoPS. Despite rather compelling arguments that a multitude of actors are necessary to explain the process of innovation (Gann & Salter, 2000), our understanding of innovation is largely limited to observations of large multi-national corporations that sit at the top of a complex network of actors that deliver CoPS (Brusoni et al., 2001; Brusoni, 2005; Davies & Hobday, 2005; Hobday et al., 2005). These are often referred to as lead firms or 'system integrators' that cultivate and maintain a network of collaborators and suppliers, and integrate their knowledge, to design and deliver CoPS to a customer (Hobday et al., 2005). The view progressed is that innovation is orchestrated by the system integrators, and they dictate the innovation activities of the rest of the supply chain (Brusoni et al., 2001; Brusoni, 2005; Davies & Hobday, 2005; Hobday et al., 2005).

The problem is that although system integrators are certainly important brokers of knowledge, they are not the single locus of innovation in these systems (Acha & Cusmano, 2005). The reality is that CoPS projects require a multitude of actors engaged in a negotiated innovation processes that plays out in particular projects (Miller & Lessard, 2000) and in the background technological progression of the industry (Gann & Salter, 2000). Many firms are necessary to produce specialised components, systems, and subsystems that ultimately comprise finished CoPS (Brusoni et al., 2001). The innovation activities that generate these constituent parts are not under the direct purview of system integrators because the breadth and depth of knowledge required is far too much for any single firm to maintain. This is the reason why innovation activities are distributed across a swath of specialised firms in the first place (Gann & Salter, 2000; Hobday et al., 2005). The development of novel product innovations is contextual and interdependent. Rather than focusing internally, project-based firms must innovate in cooperation, plugging into the opportunities presenting themselves in projects, lest their innovations not fit into the larger systems.

Second, there is some literature that attributes innovation to the project governance structures and contractual relationships therein. Governance structures refer to the decision and management structure of the project that controls the project direction and ability to solve problems and deal with exogenous shocks (Floricel & Miller, 2001). Research points to successful projects that have had the ability to absorb unexpected challenges to the project (Floricel & Miller, 2001; Lampel, 2001). Governance should be flexible and not lock management into existing commitments to such an extent that the project cannot react to changing circumstances. The governance structure could be so rigid as to disallow bringing in new firms to resolve issues, when that is the most appropriate pathway to address the problems (Floricel and Miller, 2001).

Contractual relationships refer to the specific legal contracts between firms in the project that allocate the risks of the project, and detail the reward structures for individual firm and project-level performance (Barlow, 2000). Contractual relationships are the mechanisms by which the risks and the rewards are delineated across the firms involved in the project. Equitable sharing of risks and rewards is thought to drive collaborative and innovative behaviour in the conduct of uncertain projects. Consider a highly uncertain project, such as a design for an off-shore platform situated in severe environmental circumstances like deep water. In such cases, the design of the platform may change from inception to completion because of the inherent uncertainty in the environment (Stinchcombe & Heimer, 1985). An example of equitable risk-sharing in this instance would be a project owner that assumes costs for design changes that are not knowable *a priori* (Davies et al., 2009). Inequitable risk sharing would be making the contractor pay for changes, even though that contractor would have made initial estimates based on insufficient information. The structure of risks and rewards relate directly to the levels of innovation the project achieves (Barlow, 2000; Davies et al., 2009; Gil et al., 2012; Miller & Lessard, 2000). When there is equal sharing of risks, and the rewards structure incentivises firms toward collaborative behaviours, then an innovative problem-solving culture ensues at the project level. This problem-solving culture leads to product and process innovations, as well as positive schedule and cost outcomes for the project (Barlow, 2000; Davies et al., 2009).

The focus on lead firms and project governance/contracts leaves a rather large void in our understanding of the individual innovation activities of firms that support the temporary project coalitions. In CoPS projects, we know that a host of interdependent firms—not just system integrators, but also engineering firms and product and service suppliers—comprise a network that is ultimately responsible for innovation and technological progress in CoPS industries (Gann & Salter, 2000). These networks consist of roles that individual firms perform repeatedly across the industry's projects. That is, firms occupy relatively stable positions in the network, performing specific functions that support industry projects, and represent important cogs in the overall innovation system (Gann & Salter, 2000). Because technological progress and innovation of new products are highly interdependent processes for firms in CoPS industries (Whitley, 2006), it is argued that innovation can only be explained if we understand how the many firms that support CoPS-like projects actually interrelate. That is to say, we must look to the inter-organisation interfaces that support innovation. There is actually very little known about this in the literature at present.

Central research question

Thus, the innovation literature and CoPS literature leave many questions unanswered as to how PBFs introduce novel products into highly interdependent operating environments. Thus, the central research question of this thesis is: *What factors facilitate PBFs' ability to introduce novel product innovations in environments where interdependent firms deliver complex system-level outcomes?*

2.2.2. Specific gaps

There are specific problems facing PBFs with regard to the considerable complexity of delivering novel products in a context of interdependent firms and technologies. These are: contingent opportunities for innovation; accounting for technological interdependencies, and understanding the impact of enduring inter-organisational relationship structures.

Gap #1: Contingent opportunities for innovation

PBFs are predominately concerned with the conduct of industry projects (Hobday, 1998). The development of innovation is therefore inextricably tied to opportunities that arise in projects, to the demands of the stakeholders in the projects (Acha et al., 2005), and more generally, to the technological trends that exist in the industry, which is also driven by project needs (Gann & Salter, 2000). Innovation success is closely tied to the ability of PBFs to capitalise on these opportunities while simultaneously tying into industry technological trajectories (Gann & Salter, 2000).

A review of capabilities literature is helpful to unpack the current understanding of PBFs developing novel products. Some insights from the strategic management literature may help the most, particularly the notion of ordinary capabilities, while the CoPS-related capability literature tends to focus inward on large firms, or on the projects themselves in terms of governance, offering little help. These are discussed next.

Strategic management literature

Capabilities have long been tied to innovation and firm performance. In the strategic capability literature, for instance, firm-level competitive advantage is predicated upon the way in which firms develop, maintain and utilise their individual capabilities in the pursuit of new products and services (Collis, 1994; Leonard-barton, 1992; Prahalad & Hamel, 1990). A well-known stream of capability literature is grounded in the resource-based view of the firm

(RBV), where competitive advantage accumulates from the firm's unique resources, which are recombined in different ways to render new products and services (Penrose, 1995). One particularly successful stream of literature in this vein is dynamic capabilities, defined as 'the firm's ability to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments' (Teece et al., 1997). Dynamic capabilities are thought to be means by which firms modify their existing capabilities and deliver value, often by repeatedly introducing new products in high-velocity operating environments (Eisenhardt & Martin, 2000; Teece et al., 1997). High-velocity operating environments refer to those with rapid technological change and shifting market dynamics (Hine et al., 2013; Zahra et al., 2006). Consequently, a large body of literature discusses dynamic capabilities in fast-paced industries like computing (Barreto, 2009; Eisenhardt & Martin, 2000; Teece et al., 1997). Although the literature on dynamic capabilities may have many divergent threads, in generally focuses on how firms create and maintain sustainable competitive advantage, especially in high-velocity markets—or least moderate velocity markets. Its focus is therefore not on slow incremental industrial settings (Peteraf, Stefano, & Verona, 2013).

There is a problem with this capability literature with regard to innovation in low velocity environments which typify most CoPS settings (Whitley, 2006). The underlying logic of dynamic capabilities is staying ahead of the competition by recognising and seizing opportunities in tumultuous settings and continually driving and shaping the competitive landscape through innovation activities (Teece, 2007). This suggests that innovation is premeditated and firm-centric. Contrast this with the interdependent and sometimes incremental pace of technological change that is attributed to most project based industries, due to the stable role structures and limited customer sets (Whitley, 2006). In low-velocity settings, competitive advantage and innovation activities will likely arise from the ordinary—rather than dynamic—capabilities that are attributable to the normal course of doing business for the firm (Hine et al., 2013; Winter, 2003). Ordinary capabilities might include generalised resources (in the form of staff and equipment) and stable operating routines that support the day-to-day activities the firm undertakes in performing its normal function (Hine et al., 2013). Ordinary capabilities have a more exploitative learning focus, which means there will be a propensity to innovate incrementally through slight changes and modifications to firms' offerings, as well as following the lead of others rather than approach innovation in a vanguard fashion (Hine et al., 2013; Winter, 2003). Finally, firms in low velocity environments are more likely to be near-term focused, rather than concerned with long-term strategy (Hine et al., 2013). Winter (2003) argues that the costs are high to maintain dynamic capabilities like a robust new product development routine. Such dynamic capabilities have limitations in their application, because they are predicated assumptions made by the firm as to the scope and direction of consumer trends, for instance.

Another problem is that specific routines are not particularly good at dealing with completely exogenous change for which the capability was not built. This is quite relevant for PBFs in CoPS projects, which are faced with frequent problems stemming from the interactions between component technologies—and participant firms—that need to be resolved (Atkinson et al., 2006; Chapman & Ward, 2011; Stinchcombe & Heimer, 1985). Winter (2003) argues in these cases that *ad hoc* problem solving is a particularly useful non-routine response to relatively unpredictable events, for which maintaining a specific routine-based capability would be inefficient.

CoPS and PBF literature

In CoPS literature, the discussion of capabilities relating to novel products is largely discussed in terms of the role of the system integrator (Brusoni, 2005; Davies & Hobday, 2005; Hobday et al., 2005). System integration capability is the means by which PBFs bring together the various technologies and subsystems with diverse knowledge sets to produce a complex product (Hobday et al., 2005). This capability in the modern day firm is considered paramount (Hobday et al., 2005). It reaches far beyond simply engineering integration tasks, and is the embodiment of many differentiated activities including the selection of partners, and outsourcing decisions. This perspective is limiting in two ways. First, the focus on lead firms takes focus away from the network of firms that supply components and sub-systems which are critical to understanding how innovation comes about. Second, attention on the lead firm belies the very nature of technological progression. As Hobday et al. (2005) say: “Technological advances in components and product systems to some extent shape the potential and performance of large technical systems [which they comprise], while the needs of the latter shape the pace and pattern of technical change in the former, providing a focussing device for technological efforts” (p. 1115). Thus, system integration capability in its current form does not shed much light on the capabilities needed by rest of the network.

There is also PBF capability literature that is focused on learning-related capabilities necessary to combat the temporary nature of project based organising, and is not directly related to novel product innovations *per se* (Acha et al., 2005; Brady & Davies, 2004; Davies & Brady, 2000; Gann & Salter, 2000) The learning challenge stems from project teams being physically separated from their parent businesses, and knowledge obtained in the conduct of projects is not always successfully transferred to the parent organisation, nor to the subsequent projects that the firm conducts (Acha et al., 2005; Gann & Salter, 2000; Prencipe & Tell, 2001). For instance, Acha et al. (2005) show that the structure of technology support functions (e.g., centralised vs decentralised R&D, and community of practice networks) can have impacts on learning and innovation. The idea progressed is that the structure of R&D (be it central, or distributed) is a reflection of the 'meta-routines' that the firm uses for problem solving. Ultimately, however, the links between R&D structure and routines are tenuous. The central finding—which is perhaps not insightful—is that firms investing in centralised R&D while simultaneously embedded in project tasks are likely to be novel product innovators. Acha et al. (2005) do find that having distributed networks of communities of practice (and no dedicated R&D function) might be a good method of problem solving in project execution, but that this form is inept to deliver novel insights, because such an approach is very rearward facing on past experience. However, the obvious alternative explanation is not really considered, such as the availability of slack resources to pursue novel endeavours. In all, Acha et al. (2005) do not provide much insight into the specific capabilities directly responsible for novel products in PBFs.

CoPS-related literature also exists on the use of projects as vehicles to build new capabilities (Brady & Davies, 2004; Davies & Brady, 2000). PBFs can use projects that are strategically initiated by the business (Business-led learning), or secured in the market (Project-led learning), which are highly innovative and thus are expressly used to develop the capabilities of the firm. These are called base-moving or vanguard projects, and they represent the notion of the project as a catalyst for building capabilities. However, the argument underlying these learning activities is that successful firms make these solutions repeatable by creating routines to deliver them (Brady & Davies, 2004; Davies & Brady, 2000). Thus, capability-building aligns with the goal of initial change, followed by repetition, and is not expressly tied to the ability to repeatedly create novel products. Nor does it relate to the issue of problem solving in the context of projects.

The only CoPS-related literature that does seem to address the contingent-based nature of innovation is that which is concerned with project governance structures and contractual relationships therein. The problem with this literature is that it does not take a firm-level capability perspective at all, and it only focuses on the individual attributes of projects (see prior discussion on *CoPS literature limitations* in the general gaps, Section 2.2.1).

Limitations and research sub-question

In general, there is much to be desired in the literature on capabilities useful for PBFs to introduce novel products, particularly in light of contingent opportunities. The strategic management literature is focused on higher-level dynamic capabilities, when lower level ordinary capabilities may be most suitable to explain innovation in more less tumultuous industries (Drnevich & Kriauciunas, 2011; Hine et al., 2013; Winter, 2003). In particular, *ad hoc* problem solving focused on innovative problem solving would seem more suited to the contingent nature of innovation than would dynamic capabilities for new product development (Winter, 2003). The CoPS and project literatures are focused on large PBFs and either overcoming learning challenges, or achieving competitive advantage through building internal capabilities. Neither speaks explicitly to the ability to introduce novel products into interdependent operating environments. That literature which does speak to the ability to deal with opportunities and deliver innovations is focused on the project level of analysis, lending little insight into the firm level.

Therefore, the research sub-question is: *What factors help explain how contingent opportunities are capitalised upon to introduce novel products?*

Gap #2: Technological interdependencies

The nested, interdependent nature of CoPS technologies requires firms to account for interfaces between systems and subsystems in the development of new products (Gann & Salter, 2000). Resolving these interfaces requires significant knowledge flows across firm boundaries (Acha, 2008), and in particular with customers and suppliers directly involved in the projects that the firm is participating in and supporting (Gann & Salter, 2000; Manley, 2008). Tacit knowledge dimensions are thought to be particularly important for PBFs in the resolution of these interfaces, due to the close working relationships between firms in the development of collective innovations within project contexts (Gann & Salter, 2000).

The innovation literature has long sought understanding of how firms engage with each other to develop innovative products, with a strong focus on knowledge flows (Cohen & Levinthal, 1990; Zahra & George, 2002). In particular, 'open innovation' is an increasingly important perspective on the purposeful knowledge transfers across firm boundaries for the purposes of innovation (Chesbrough & Bogers, 2014; Chesbrough & Crowther, 2006; Chesbrough, 2003; Dahlander & Gann, 2010; Laursen & Salter, 2006; West & Bogers, 2013). In this regard, attention has been drawn to the importance of both in- and out-bound forms of open innovation, including pecuniary activities like licensing and patenting, and non-pecuniary activities like searching for information and revealing details about internal innovations to others (Chesbrough, 2003; Dahlander & Gann, 2010). A recent definition of open innovation is the 'purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for the external use of innovation' (Chesbrough, 2012 p.20). Dahlander and Gann (2010) identify the need to consider non-pecuniary forms of openness, which are not transactional. A more recent definition reflects this notion: 'Open innovation as a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with the organisation's business model (Chesbrough and Bogers, 2014 *via* West et al., 2014, p.806).

Dahlander and Gann's (2010) typology identifies four types of open innovation created by a 2x2 matrix comprised of inbound/outbound, and pecuniary/non-pecuniary knowledge flows. See Figure 3.

	Inbound innovation	Outbound innovation
Pecuniary	Acquiring In-licensing, adopting or buying expertise or technology from external sources	Selling How firms protect, appropriate value from, and commercialise their intellectual property and technological artefacts
Non-pecuniary	Sourcing Leveraging existing external sources of information for innovation purposes	Revealing Sending information to the external environment selectively, in order to spur problem solving or aid in the diffusion of innovations

Adapted from Dahlander and Gann (2010)

Figure 3 - Open innovation typology

Out-bound, pecuniary *selling* is characterised by Dahlander and Gann (2010) as the transactional activities relating to outbound intellectual property (IP) or technology flows. It is closely tied to the appropriability literature, particularly that which speaks to the importance of patenting, out-licensing, and secrecy as means to capture value from innovations (Cohen et al., 2000; Laursen & Salter, 2014).

Inbound, pecuniary *acquiring* involves the adoption and/or in-licensing of technology and/or IP from outside of the firm (Dahlander & Gann, 2010). Examples range from intangible assets (software program or a design) and technical know-how in the form of technical services to patented technology artefacts (Arora et al., 2001, p.422).

Inbound, non-pecuniary *sourcing* is the act of inducting external information that does not have direct costs for the purposes of innovation (Chesbrough & Crowther, 2006; Dahlander & Gann, 2010). A popular construct for inbound information flows is search breadth (Chiang & Hung, 2010a; Garriga, von Krogh, & Spaeth, 2013; Laursen & Salter, 2006; Leiponen & Helfat, 2010). Search breadth is often operationalised by the extent to which a set number of external information sources are used to support firms' innovation activities (Laursen & Salter, 2006). Broad search seems to be positively related to novel innovation in a number of settings including US robotics firms (Katilia & Ahuja, 2002) and UK manufacturing industries (Laursen & Salter, 2006), to Taiwanese electronic firms (Chiang & Hung, 2010a). For example, in Finish manufacturing firms, broad search explains both the likelihood that product innovations will be introduced, and the relative success of those innovations (Leiponen & Helfat, 2010). Chiang and Hung (2010) find that Taiwanese manufacturing firms that search broadly have higher novel innovation performance. Chen et al., (2011) show that broad search is positively related to innovative performance in Chinese firms from several different industries.

Outbound, non-pecuniary *revealing* is outbound disclosure of knowledge to the public or external environment without any immediate prospect of compensation or reward (Dahlander & Gann, 2010). Revealing is increasingly being used as used as a customer co-development strategy (Henkel & Baldwin, 2010). Henkel et al. (2013) cite the Linux software industry as an example of how revealing with customers has given rise to a co-development capability that has since become a key competitive differentiator for firms. They argue that customers initially compelled firms into revealing software drivers. Revealing was initially demanded by customers that wanted to participate in the development process. Soon afterward, these practices became ingrained in the industry—partially stemming from positive feedback from customers, and partially from internal recognition that revealing (including often waiving IP rights entirely) helped to speed up the firms' product development efforts. Thus, revealing has become part and parcel to product development efforts, and a competitive differentiator for firms operating in this the software industry.

Non-pecuniary knowledge flows are argued to be the most important aspects to consider for PBFs, because of the network-like structure of relationships that govern coordination and innovation (Gann & Salter, 1998, 2000; Jones et al., 1997; Jones & Lichtenstein, 2008). Networks are structured patterns of relationships between individual firms engaged in the creation of novel products[4] (Jones et al., 1997). In networks, firms know

[4] Networks are particularly good for transmitting tacit knowledge vis-à-vis innovation. Tacit knowledge has been described as that which you know but cannot explain or is undefinable (Polanyi, 1962). The transfer of such knowledge, particularly with regard to innovation development and diffusion, requires close working relationships between buyer and seller (von Hippel, 1994). Network forms of organising facilitate these

each other because they have a history of previous interactions, and thus have a great deal of firm-specific knowledge that makes them highly interdependent (Jones & Lichtenstein, 2008; Powell, 1990). Gann and Salter (2000) note that relationships in CoPS industries are not purely buy-sell, and this is particularly true in the way that innovation is managed (Gann & Salter, 2000). Consider the opportunity for non-pecuniary knowledge flows in the following examples of practices that PBFs engage in: long-term partnerships and alliances (Jones & Lichtenstein, 2008); co-engineering practices (Gann & Salter, 2000); integrated equipment and service agreements where product suppliers are embedded into the buyers' operations to provide integration and continued operation and maintenance support (Davies et al., 2007; Gann & Salter, 2000); and pooling intellectual property with competitors in a proposal to increase the chances of winning a new project with a client (Davies et al., 2011). Each of these practices is predicated on the desire and need to share detailed tacit knowledge about the technologies and innovations that are being produced. The activities are the embodiments of know-how, and know-who, which are tacit knowledge dimensions necessary to conduct CoPS projects and develop innovations (Gann & Salter, 2000). That is, PBFs draw on ideas from the network and then work iteratively with customers and suppliers and other project participants in order to successfully translate these ideas into novel product innovations within project contexts (Manley, 2008). The high-quality sharing of tacit information to support such innovation outcomes is a result of the network form of organising (Jones et al., 2007).

Limitations and research question

Open innovation provides a conceptually appealing means to address technological interdependency issues in PBFs. However, there is little current understanding of how open innovation practices operate within networks (Vanhaverbeke, 2006; West et al., 2014), and, of course, this includes PBFs operating CoPS settings (cf: Acha, 2008). The importance of cross-boundary knowledge flows across inter-organisational networks is well known to support the development of innovation (Fabrizio, 2009; Powell et al., 1996) and the capturing of value (Vanhaverbeke, 2006) in industry settings like biotech. However, less attention has been paid to firms operating in settings where inter-organisational collaboration is more frequent, such as those involved in the design and delivery of innovative CoPS (Hopkins et

frequent interactions between firms. Networks are comprised of the underlying relationships between firms that are formed and maintained to support the conduct of highly customized tasks that rely upon highly specialised knowledge (Jones et al., 1997). Jones et al. (1997) remark that the cascade of recent biotech innovations might rest directly on the ability of network relationships to rapidly spread tacit knowledge in particular.

al., 2011).

Another problem is that only recently have researchers begun to focus on both inbound and outbound types of open innovation within the same study (Laursen & Salter, 2014). For instance, Laursen and Salter (2014) established that inbound search was linked to the number of appropriability strategies (including patenting, and secrecy) that manufacturing firms tended to use. Without looking at both inbound and outbound activities in the same study, there is no means to explicate their relative importance or their coupled nature (Gassmann & Enkel, 2004).

For the purposes of resolving inter-dependencies, PBFs would tend to use non-pecuniary activities of inbound *sourcing,* and outbound *revealing,* because these are most likely conduits for tacit knowledge flows that underpin innovation activity. Using this as a basis, the research question posed is: *What is the relationship between inbound and outbound knowledge flows and novel product innovation?*

Gap #3: Role of enduring inter-organisational relationships

PBFs operate within an enduring network of relationships that persist over time (Bakker, 2010; Jones & Lichtenstein, 2008; Manning & Sydow, 2011; Sydow, Lindkvist, & DeFillippi, 2004; Sydow & Staber, 2002; Whitley, 2006) . The conduct of inter-organisational projects, while temporary in nature, are conducted in a context that is much more permanent, consisting of institutional stability (Sydow & Staber, 2002), role stability (Bechky & Okhuysen, 2011; Bechky, 2006; DeFillippi & Arthur, 1998), and inter-organisational relationship stability (Jones & Lichtenstein, 2008; Windeler & Sydow, 2001).

These stable roles and relationships between firms then constitute a project network which is the fabric from which new projects are made (Cattani et al., 2011). Project networks are actually built upon repeat collaborations across projects and over time (Bakker, Knoben, de Vries, & Oerlemans, 2011; Jones & Lichtenstein, 2008). PBFs interact in similar capacities in multiple projects, often teaming or collaborating with the same firms or groups of firms (Eccles, 1981). In project-based settings, this repetition increases the levels of trust between firms, familiarises firms with each others' operating routines, and decreases transactional and market uncertainty (Jones & Lichtenstein, 2008) . These attributes of project networks allow firms to assemble in new combinations over time and deliver complex inter-organisational outcomes (Hellgren & Stjernberg, 1995).

In CoPS settings and many other project-based industries, firms tend to maintain relatively stable role positions and enduring inter-organisational relationships (Jones et al., 1997; Jones & Lichtenstein, 2008; Sydow et al., 2004; Sydow & Staber, 2002; Uzzi, 1997). Stable network structures are typical of low-velocity industries with a slow pace of technological change (Whitley, 2006), such as upstream oil and gas (Noke et al., 2008). This is because these industries have small numbers of ultimate customers, and thus the relationships between firms and lead system integrator firms remains relatively stable over time (Jones & Lichtenstein, 2008; Whitley, 2006). These semi-stable roles provide the necessary framework for firms to effectively coordinate the development of new products and services that support the industries' business projects, innovation endeavours, and technological change processes (Gann & Salter, 2000; Gann, 2000).

The concept of enduring relationships is rooted in the social capital literature on embeddedness (Granovetter, 1985; Uzzi, 1997). Granovetter's (1985) original treatise on embeddedness argued that networks, which are comprised of enduring social relationships and inter-relational structures, have great influence over economic activity, particularly in terms of how firms choose to engage in inter-organisational exchanges. He argued that the (then current) theorising on economic action placed too much attention on cost-minimising behaviour of managers, and did not adequately address the embedded network of social ties that permeate economic activity, both inside and outside the firm. The alternative view he progressed in the inter-organisational context was that engagement with external parties is driven by a number of alternative social reasons ranging from simple managerial preference, to more inertial proclivities such as using existing partners because they are perceived to be less risky. Importantly, he argued that networks of this sort help to discourage malfeasance and resolve conflict since these enduring social connections inculcated trust and manifested as behavioural norms[5]. In effect, his argument established that social embeddedness is just as likely an inter-organisational coordination mechanism as formal contracts and market relationships.

Subsequent work has highlighted the relative benefits of network embeddedness. Uzzi's (1997) study on clothing firms found that trust between actors in the production allowed a special kind of heuristic decision making process that saved time and still produced quality outcomes. He also found that embeddedness supported the transfer of 'fine-grained' tacit knowledge considered to be too difficult to convey across arms-length market agreements. Importantly, Uzzi also found that embeddedness facilitated problem solving

[5] Granovetter also recognized the downsides, noting that social embeddedness also was a likely precursor to particular classes of malfeasance that could only be perpetrated upon actors when close social ties exist, like embezzlement.

routines that promoted adaptation, learning and innovation.

Embeddedness has also gained prominence in the project literature (Bakker et al., 2011; Bakker, 2010; Eccles, 1981; Jones & Lichtenstein, 2008). Specifically, embeddedness plays two critical roles—reducing transactional and demand uncertainties—which are prevalent in project-based settings. Each is discussed next.

First, transactional uncertainty refers to the potential for malfeasant behaviour (Grannovetter, 1985), or moral hazards in the language of transaction cost economics (Williamson, 2008), referring to unfair shifting of risks (and associated costs incurred from them) between parties engaged in an economic exchange. This potential is reduced when firms are embedded in a network that is comprised of repeat collaborations, because this repetition facilitates a shared understanding of each others' roles and capabilities (Bechky, 2006; Jones & Lichtenstein, 2008). In this way, embeddedness reduces transactional uncertainty because firms already know the reputation of the exchange partner, and have expectations about performance, and to some extent this enhances coordination between the firms because they are aware of one another's routines and preferences (Jones & Lichtenstein, 2008). In terms of transaction cost economics, these contractual relationships would reflect a benign or credible contracting approach where uncertainty is reduced through forward thinking, cooperation and mutual adaptation; governed by trust between actors (Williamson, 2008).

Reduced transactional uncertainty has positive implications toward innovation. Specifically, knowing each others' roles and behaviours helps to promote improvisational responses to unexpected challenges and disruptions in projects (Bechky & Okhuysen, 2011). This type of coordinated response is important in CoPS industries like oil and gas in particular, because innovative problem-solving is a core activity in the conduct of these complex projects (Ahola & Davies, 2012; Barlow, 2000; Stinchcombe & Heimer, 1985). Embeddedness would facilitate fast problem solving in the face of project time limitations (Bakker, 2010). It would also explain how the considerable coordination burden associated with complex problem solving innovations is overcome (Nightingale, 2000; Thompson, 1967).

Second, embeddedness helps to reduce demand uncertainty, which is the unknown future expectation for the services of the PBF by the market over time. Embeddedness helps address this by allowing dormant relationships to quickly be reinstated, and allowing the creation of new combinations of firms inside new inter-organisational projects to address innovation challenges (Grabher, 2002; Hobday et al., 2005; Iacono et al., 2012; Jones and

Lichtenstein, 2008; Manning and Sydow, 2011). For instance, aircraft system integrators address new innovation projects by making unique combinations of network partners (Davies & Hobday, 2005). Enduring relationships reduce search costs and decrease time that would be spent building alternative trust-based relationships (Bakker et al., 2011; Granovetter, 1985; Jones & Lichtenstein, 2008; Manning & Sydow, 2011; Meyerson et al., 1996). Whitley (2002) identifies that supplier and customer embeddedness are particularly important vis-à-vis innovation in industry networks. Thus, this section pays close attention to these vertical relationships with suppliers and customers in terms of their impact on the introduction of novel products. It reveals some positive support for each type of embeddedness, and little direct evidence regarding over-embeddedness.

Supplier embeddedness

Suppliers are a useful source of expertise and knowledge about sub-system and component technologies, which are important inputs into technological development (Tsai & Wang, 2009). From a knowledge-based perspective, the diverse knowledge embodied separate suppliers can provide very useful sources of knowledge for combinatory innovation activities (Grant, 1996; Kogut & Zander, 1992). Importantly for PBFs, the distribution of such knowledge across multiple supplier firms is necessary because the scope of knowledge required to manufacture components and sub-systems that comprise CoPS is so immense that no one firm could maintain it (Brusoni et al., 2001; Brusoni, 2005). Collaborations with suppliers are most helpful in gaining knowledge quickly about the movements and trends in source technologies, and the process improvements underlying them (Whitley, 2002). Close collaborations with suppliers allow firms to shift strategies rapidly, and achieve novel innovation outcomes more effectively (Nieto, Santamaría, & Santamaria, 2007).

Theoretically then, supplier embeddedness would seem to be supportive of novel product innovation for all firms. The direct empirical evidence from CoPS literature or supplier embeddedness specifically is slim, but in general the innovation literature points to a positive relationship between supplier relationships and innovation. For Taiwanese manufacturers, supplier collaborations appear to be vital to new product innovation performance in this industry, but the effect is only present with commensurate research and development intensity (a proxy for absorptive capacity) (Tsai and Wang, 2009). Nieto and Santamaria (2007) show that Spanish manufacturing firms with exclusive collaborations with suppliers are more important to novel product innovation outcomes than exclusive collaborations with customers or with universities. Koufteros et al. (2007) look at the role of suppliers in the co-development of product innovations for 157 US manufacturing firms and found direct positive relationship between supplier involvement and returns on product innovations.

However, there is conflicting evidence about the relationship between supplier engagement and innovation, which is likely due to timing of the collaboration in terms of the stages of innovation development (Knudsen, 2007; Wagner & Hoegl, 2006). For example, for European manufacturing firms from a variety of sectors, Knudsen (2007) finds direct supplier involvement in the ideation stage positively impacts performance (as percent of sales from new products). However, no such relationship is found at the commercialisation stage. A similar pattern is seen in the novel product innovations in a variety of US technology industries (Tidd & Bodley, 2002). On the contrary, Song and Thieme (2009) found in their analysis 315 high technology firms that market intelligence provided by suppliers generally detract from novel innovations when heavily used in development stages.

Returning to PBFs, in CoPS industries firms tend to integrate very closely with suppliers, because strong and enduring relationships with many specialised suppliers are a necessity of delivering CoPS (Davies & Hobday, 2005; Hobday et al., 2000). At the highest level, system integrators facilitate innovative outcomes by directly incorporating suppliers into integrated design and engineering teams (Brusoni, 2005; Martinsuo & Ahola, 2010), and also engage in long term service contracts to aid in integration, operation and maintenance of sub-systems (Brusoni, 2005; Davies et al., 2007; Gann & Salter, 2000; Geyer & Davies, 2000; Salunke, Weerawardena, & McColl-Kennedy, 2011). But the benefits of supplier collaborations would not stop at the system integrator, rather because of the nested nature of CoPS, supplier relationships would be important down the levels of the project network. An indication of this is found in data on small PBFs that are not managing CoPS systems at the highest level. For instance, small UK construction firms have been shown to be reliant upon their suppliers to facilitate product innovations (Reichstein et al., 2008), and small Australian construction firms heavily rely on their suppliers to provide complementary knowledge and skills necessary to overcome internal resource shortages and meet project-related innovation challenges (Manley, 2008).

Customer embeddedness

The innovation literature strongly suggests that there is a positive relationship between customer involvement and innovation. Customers and end users are recognised to be highly influential in the development of novel product innovation outcomes (von Hippel, 1988, 2007). This is because new product innovation is often driven by the needs of lead users who have emergent idiosyncratic needs (von Hippel 2007). These users often invent and develop prototypes only later to have the innovations be built at full scale, for the benefit of other firms (von Hippel 2007). In the development and adoption of user innovations, tightly coupled and iterative problem solving occurs between the supplier and the customer in order to overcome integration and operationalisation (Von Hippel 1994). As technological novelty increases, this close collaboration with customers becomes a critical success factor because problem-solving activities increase in their complexity (Hippel, 1994; Shenhar, Tishler, Dvir, Lipovetsky, & Lechler, 2002). Empirical findings from the innovation literature support this theoretical contention that customers positively influence innovation. Chinese manufacturing suggests that customer orientation and use of inter-functional teams are factors supporting novel innovations (Atuahene-Gima, 2005). Nieto and Santamaria (2007) find for Spanish manufacturing that exclusive collaborations with customers are positively related to novel product innovation (although the effect is less than that for exclusive collaborations with suppliers).

In CoPS settings in particular, there is a very tight link between customers and the innovative projects that they commission, because these are most often bespoke instantiations demanded by a limited customer set (Hobday, 1998). In the process of developing these tailored innovations, suppliers must react to clients' shifting requirements and needs (Barrett & Sexton, 2006). This activity is evident in the oil and gas industry, where the innovation and diffusion of product technology is tightly linked with projects (Bower et al., 1997; Daneshy & Donnelly, 2004). For instance, new product technologies are necessarily tested directly within customer's exploration and production projects (Bower et al., 1997).

CoPS empirical literature reveals both positive and negative relationships between customer embeddedness and innovation. On the positive, it has been found that collaborations with customers are twice as likely in complex system projects across the UK's chemical, pharmaceuticals, durable goods, and food sectors where customer involvement is important to facilitate commercialisation of the novel technology (Tidd & Bodley, 2002). In a review of the UK construction industry, Reichstein et al. (2008) reveal that using high levels of customer input increases the odds of product innovations by six times over firms using low levels. These authors speculate that this is due to the significant involvement of clients, in early design and production stages of projects, who articulate their vision and drive technology decisions (Reichstein et al., 2008). Similarly, from studying novel product innovations in small Australian construction firms, Manley (Manley, 2008) finds that product innovation is improved when firms work closely with clients who have high technical steering competency.

On the negative side of the argument, in CoPS industries like construction and oil and gas, customers have distinct reputations for being incrementally innovative (Barrett & Sexton, 2006; Daneshy & Donnelly, 2004; Hardie & Newell, 2011; Keegan & Turner, 2002; Manley, 2008; Reichstein & Salter, 2006). In these environments, customers may view innovation as costly, risky and even dangerous (Keegan & Turner, 2002). In construction in particular, customers have strong reputations for disfavouring novelty, instead placing preference upon tried and true technologies (Barrett & Sexton, 2006; Daneshy & Donnelly, 2004; Hardie & Newell, 2011) that have clearly demonstrated cost savings in other projects (Manley, 2008).

Over-embeddedness with suppliers and customers

First, it must be stated that over-embeddedness has not directly been studied for PBFs. In any case, although supplier over-embeddedness is not an explicit focus of study, there are tangential empirical examples indicating that there may be continued positive benefits at high levels. For instance, Berghman et al., (2012) analysed 182 industrial firms in The Netherlands and they find that increasing levels of information obtained through normal collaborative working relationships with suppliers played an important role in the ability of the firm to take innovation information and translate it into novel innovations. In construction, Dubois and Gadde (2000) argue that very embedded relationships with suppliers help firms to develop complementary knowledge sets that are inextricably linked, and subsequently have a positive bearing on the ability to develop new technology.

Customer over-embeddedness, on the contrary, may appear to have some innovation downsides. Although there is not much direct research on over-embeddedness, there is tangential evidence. For instance, the innovation literature suggests that firms heavily reliant on customer input are not likely to innovate in truly radical and disruptive ways (Christensen, 2003). This is because customers will always tend to prefer incremental improvements of existing products, placing pressure on the focal firm to maintain current product offerings, and thus result in incremental innovations rather than radical changes to product architecture that disrupt (Atuahene-Gima, 2005; Christensen, 2003; Leonard-barton, 1992; Levinthal & March, 1993; March, 1991). Recent empirical examples from innovation literature show a deleterious effect on innovation resulting from extensive customer involvement. For instance, Knudsen (2007) finds a negative relationship between customer involvement and the performance of new products in five different industries in Europe, particularly when involvement extends across the process, from ideation to commercialisation. Knudsen suspects the short term/application-oriented focus of customers leads to incremental changes and tailored products that are too specific to appeal to wider customer sets. Berghman et al., (2012) study firms in the Netherlands, and find a negative relationship between heavy customer input in the commercialisation stage and novel innovation performance. They argue that this is because customer input is more critical in the development stages, but Knudsen's (2007) argument is a plausible alternative explanation.

Vertical or dual embeddedness

Whitley (2002) argues that firms deeply ingrained in industry networks are limited in their ability to innovate in novel ways. Concurrent obligations with suppliers and customers in particular lead firms into incremental technology trajectories because the focal firm is locked in step with the industry progression as dictated by customers and suppliers. Further, Whitley (2002) argues that firms that choose to break out of these constraints may suffer reputational damage. This is because novel innovation displays a willingness to break technological norms and could dissuade future collaborators that want reliable technology partners and low risk solutions.

Not much empirical work, however, was found about the relationship between high levels of embeddedness with both customers and suppliers. Although there are limited data directly from project-based industry settings, innovation literature shows that customer embeddedness may adversely affect the innovation potential of other collaborations (Knudsen, 2007). For example, for UK firms in a range of industries, customer involvement in new product development projects negatively impacted novel product innovation performance when those products were developed with universities or competitors (Knudsen, 2007). Thus it appears customers may suppress innovation potential of other collaborations.

Limitations and research question

One limitation of this prior work relative to CoPS is the focus on the system integrator. The discussion of embeddedness is implicit in the discussions about how system integrators maintain a number of key partners and suppliers, and marshal these resources to conduct inter-organisational innovation projects to develop new CoPS (Davies & Hobday, 2005; Hobday, 1998; Nightingale, 2000; Söderlund, 2002). For instance, system integrators tend to maintain strong relationships with a select few large project-based firms (e.g., global construction, engineering, and architecture firms) and specialist technology providers, interacting repeatedly with them and developing lasting relationships (Jones and Lichtenstein, 2008). This top-level embeddedness affords system integrators the ability to recombine and reconfigure relationships to solve many new CoPS-related challenges for customers, allowing firms to strike the necessary innovation balance between old and new (Ahola & Davies, 2012).

This literature also argues that lower-tier firms (those that are smaller and supply parts, components, and materials) are argued to be less effected by embeddedness because they may work for a variety of different customers (Jones & Lichtenstein, 2008). However, this view is disconcerting, because an increasing amount of novel product innovations comes directly from the lower tiers of the project networks in the form of components and subsystems (Brusoni, 2005; Davies & Hobday, 2005; Gann & Salter, 2000), and these firms are known to maintain stable roles in the CoPS innovation ecosystem (Acha et al., 2005; Gann, 2000). Yet, we know very little about these roles and collaborations at lower levels, because they are rarely studied (Acha et al., 2005; Blindenbach-Driessen and van den Ende, 2006; Cattani et al., 2011; Hobday et al., 2000). Therefore, there appears to be a rather large gap in our understanding of embeddedness in CoPS networks, beyond the system integrator level.

Another limitation of prior work is what little attention has been paid to the potentially detrimental impacts of embeddedness. The social capital literature argues that well-connected (dense) networks may hinder innovation potential because firms are repeatedly exposed to information that is re-circulated from their immediate connections and are not exposed to novel information from loosely connected parts of the network (Burt, 2004; Uzzi & Spiro, 2005; Uzzi, 1997). Over-embeddedness essentially insulates firms from new possibilities (Uzzi, 1997). A similar theoretical argument on over-embeddedness in project-based industries is progressed by Whitley (2002). He argues high levels of industry network involvement, specifically intense collaboration with industry partners, particularly suppliers and customers, will limit the degree of innovation that firms can be expected to undertake. He also suggests that mutually interdependent commitments promote increasingly customised yet incremental solutions, which lock firms into pre-ordained technological trajectories. High levels of network involvement thus limit the capacity of firms to undertake truly novel innovation. This threat, in turn, signals a lack of commitment to the network partners, erodes firm reputation, and thus further threatens its position in the innovation network (Whitley, 2002).

In sum, this subsection has shown while there is little direct evidence, there is some support for the contention that some supplier or customer embeddedness may have positive impacts on novel product innovation. However, the literature is devoid of much theoretical speculation or any empirical evidence of the effect of over-embeddedness, although there is some support for the notion that too much customer involvement is bad. Nor has the effect of 'dual' embeddedness with both suppliers *and* customers been studied (Whitley, 2002).

All of these gaps relate to structural embeddedness, which refers to enduring inter-organisational connections (Rowley et al., 2000). Thus research sub-question is: *What is the relationship between structural embeddedness and novel product innovation?*

2.3. Approach to filling the gaps

2.3.1. Capabilities to address contingent opportunities

In terms of capitalising on contingent opportunities for novel product innovation in low-velocity settings, firms may use a combination of *ad hoc* problem solving and ordinary capabilities to develop innovations (Winter, 2003). *Ad hoc* problem solving is argued to be essential to address unpredictable nature of problems that accompany large engineering projects (Stinchcombe & Heimer, 1985). Ordinary capabilities are required to conduct the normal day-to-day activities of PBFs, which in this case includes supporting inter-organisational industry projects. Two capabilities relating to *ad hoc* problem solving and ordinary capabilities that are missing from the literature are called *adaptive problem solving* and *networking*. The next sections discuss how firms use adaptive problem-solving capabilities to resolve uncertainty within industry projects and to produce problem-solving innovations. The section after that discusses how basic networking capabilities allow project-based firms to connect to and leverage partnerships toward innovative ends.

Adaptive problem solving

Adaptive problem solving appears to be a major success factor in many complex engineering projects, and is often the catalyst for innovative solutions that contribute to project success (Barlow, 2000; Davies, 2013; Floricel & Miller, 2001; Nightingale et al., 2011; Stinchcombe & Heimer, 1985). The importance of adaptive problem solving is no better stated than by Stinchcombe (1985), who in his seminal work on North Sea oil and gas projects argued that all aspects of a project should be administered as if they were innovative responses to uncertain events (Ahola & Davies, 2012).

The reason that adaptive problem-solving capabilities are such a prevalent activity in CoPS industries is because they deal with the considerable uncertainty that stems from complex interactions between the many moving parts of large inter-organisational projects.

Before denoting these sources of uncertainty, it is useful to explain the emergent behaviour of complexity. To help explain how interactions give rise to uncertainty in projects, it is useful to think of them as complex systems. Simon (1962) defines a complex system as '…one made up of a large number of parts that interact in a non-simple way. In such systems, the whole is more than the sum of the parts, not in an ultimate, metaphysical sense, but in the important pragmatic sense that, given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole' (p. 468).

In large projects, there are arguably two major sources of uncertainty—technological and inter-organisational. First, there is considerable technological uncertainty in large projects that is related to the collapsed nature of the innovation in which conception, design and delivery occur within a single project. This is a protracted process that can last two years in the case of offshore oil and gas projects (Barlow 2000) and up to ten years in the case of very large engineering projects like dams (Miller and Lessard 2000, 2008). Although uncertainties in the design and technology choices are naturally reduced over time as the project nears completion, in highly complex projects these uncertainties never completely diminish (Jaffari 2006).

Technical complexity arises from a number of components inside systems (Baccarini, 1996; Nightingale, 2000) and between interacting systems (in the case of array or systems of systems projects) (Shenhar & Dvir, 2007, 1996). Nightingale et al., (2011) lay out the sources of variation that underpin technological uncertainty in CoPS, and the mechanisms that give rise to multiple interacting problem-solving activities. First, they argue that project plans are statements of desire rather than fact (an epistemological distinction that distinguishes temporary organising from permanent organisational types that perform repetitive actions). This distinction means that PBFs may attempt several approaches to achieve desired outcomes, and some attempts will lead to dead ends and rework that will cost time and money. Second, this process repeats and can lead to multiple additional sub-problems that may themselves be interdependent, causing complex feed-back loops and redesign efforts that cannot be anticipated *ex ante*. A third source of variation is that the prior two sources in the project (that affect costs) also change the potential *value* to the customer, which in turn can reframe the stated (desired) outcome. Further, Nightingale et al., (2011) argue that the number of iterations of problem solving is related to the number of tasks. Hence, larger projects have more tasks, and more problem solving subtasks, and this increases the number of iterations and feedback loops. They also argue iteration increases with less mature core technology, with high interdependences between the tasks and the underlying technologies, and the clarity of the customer's desires.

Looking more broadly, technology also interacts with the environment and this is another source of uncertainty in large engineering projects (Miller & Lessard, 2000; Scott et al., 2011; Stinchcombe & Heimer, 1985). Complex interactions between the technologies and the environments in which they are used create new and anticipated risks (Miller & Lessard, 2000). For instance, off shore oil platforms face extreme and unpredictable weather conditions or extreme operational parameters (such as ultra deep water wells) that often means initial designs may not reflect the finish product (Barlow, 2000; Stinchcombe & Heimer, 1985).

The second major source of uncertainty is inter-organisational, and is simply a result of the ways that sometimes hundreds of firms with diverse roles including design, engineering, supply and construction are involved in solving problems as they drive toward final solutions (Davies et al., 2009; Gann & Salter, 2000; Gann, 2000; Miller & Lessard, 2000; Scarbrough et al., 2004). The sophistication of the division of labour in such settings results in emergent properties that cannot be predicted beforehand (Nightingale, 2000). These properties stem from conflicts related to resource commitment and communication issues inside firms, and outside firm boundaries, as the team iterates to find design solutions (Nightingale, 2000). On the scale of the large project endeavours, these small interactions multiply to produce unforseen and emergent outcomes, especially with the sprawling global supply chains necessary to support today's megaprojects (Kardes et al 2013).

What adaptive problem-solving capabilities look like

Considering the uncertainty-ridden environment that PBFs participate in, problem solving capability seems quite appropriate and necessary to explain innovation in PBFs. Three suspected elements of this capability are discussed next.

First, as discussed above, the projects that PBFs participate in are inherently inter-organisational problem-solving activities (Ahern, Leavy, & Byrne, 2013; Ahola & Davies, 2012; Davies, 2013; Nightingale & Brady, 2011; Söderlund, 2002; Stinchcombe & Heimer, 1985). More succinctly, complex projects are typified by uncertainty, and this uncertainty gives rise to risks, events and opportunities inside projects that require innovative problem solving (Nightingale et al., 2011; Stinchcombe & Heimer, 1985). The ability to problem solve in large engineering projects has directly been tied to the development of product innovations (Barlow, 2000; Davies et al., 2009). Two empirical examples help explain how this works. First, Barlow (2000) describes the BP Andrews offshore oil platform as having high levels of problem solving, which led to a number of product innovations. According to Barlow (2000), this project was the first time an offshore oil platform was completely fabricated on shore before being transferred to sea. The project required the design, production, and installation of an integrated drilling and production platform and underwater pilings and substructure to support the platform in 116m of water. Because of the constraints imposed in both fabrication and transport, the team engaged in design innovations that ultimately reduced number of pilings used on the substructure (the support structure of the oil production platform) was reduced by four (from 16 to 12) and resulted in a savings of £2m. Other innovations involved the waterproofing procedure on the substructure that saved another £1m. The size of the pipeline was able to be reduced by 20 per cent, and this allowed the project to be brought online six months ahead of schedule garnering early revenues. A second example is the Heathrow Terminal 5 expansion project (Davies et al., 2009). Davies et al., (2009) describe the implementation of several innovations that were a result of the considerable time pressures placed on the project, and physical constraints on materials staging areas. For instance, the team adopted three dimensional modelling in the design concrete subassemblies instead of commonly used physical prototypes. This approach conferred important schedule and cost savings because it economised the design process by speeding up the development and assessment of novel concrete designs. Other process-related innovations relate to delivery of materials. The expansion project was constrained severely in terms of physical foot print because the other airport terminals were still in full use. This constrained both the timing and the pathways for the delivery of physical structures and materials. These severe constraints resulted in the development of a sophisticated, inter-organisational just-in-time (JIT) material staging facility and delivery management software.

A second component of adaptive problem-solving capability regards the ability to adapt to changing circumstances in projects. The most successful firms] adeptly manage all sources of uncertainty, closely monitoring progress and adapting long before changes become costly (Atkinson et al., 2006). Further, when new risks emerge, prescient firms realise that these are not necessarily negative, but can represent ‘opportunities’ (Jaafari, 2001; Perminova et al., 2008). Perminova et al. (2008) explains this potential upside: *‘a context for risks as events having a negative impact on the project’s outcomes, or opportunities, as events that have beneficial impact on project performance’* (p. 76). Firms must maintain vigilance, paying close attention to these changes and opportunities in order to capitalise upon them (Loch, DeMeyer, & Pich, 2006; Zhang, 2013). Taken together, a PBF which is amenable to change, can view an unforseen circumstance as an opportunity for innovation, and will be more likely pursue new product developments.

A third critical component of adaptive problem-solving relates to firms' ability to remember and reuse problem solving heuristics in the future. Specifically, firms displaying an adaptive capability would have the means to transfer knowledge relating to prior problems, and their innovative solutions, across to future projects (Brady & Davies, 2004; Davies & Brady, 2000; Gann & Salter, 2000; Prencipe & Tell, 2001). However, this is difficult in practice for project-based firms because they lack the more permanent hierarchy that traditionally serves to remember and/or codify knowledge, causing the knowledge to remain tacit (Brady & Davies, 2004; Davies & Brady, 2000; Prencipe & Tell, 2001), and therefore not necessarily routinised into a higher-level dynamic capability (Winter, 2003). Firms that are able to transfer learning, therefore, are less likely to repeat past mistakes and are more likely to transfer ideas and innovations from prior projects into future ones.

Networking capabilities

Strategy scholars have increasingly argued that networking is an important but neglected capability perspective on innovation, because competitive advantage can accrue by leveraging external network relationships (Dyer & Hatch, 2006; Gulati, Nohria, & Zaheer, 2000; Mcevily & Marcus, 2005; Zaheer & Bell, 2005). Inter-organisational relationships can provide important sources of knowledge that can form the basis of new capabilities (Mcevily & Marcus, 2005). In particular, trust-based relationships and joint projects—particularly those involving customers, suppliers, and other network partners—facilitates information-sharing that becomes the source of new competitive skills, including those that support new product development (Mcevily & Marcus, 2005). Capabilities of this sort may improve firm performance (Zaheer & Bell, 2005) and contribute to long-term competitive advantage (Dyer & Hatch, 2006; Gulati et al., 2000). Network connections can facilitate trust, and subsequent tacit information sharing can lead to novel product innovation (Ahuja, 2000). Network relationships are valuable in helping focal firms evaluate the value of information for from external partners (Ahuja, 2000; Rost, 2011). Further, redundant network ties might lead to higher innovation potential in general (Hagedoorn & Duysters, 2002). However, this view of networking is derived from the study of high-velocity environments such as biotechnology and computing where characterised by rapid technological change and high rates of novel innovation. There is lesser understanding of the role of networking capability in low-velocity environments.

Networking capabilities are very important in explaining innovation in CoPS-like industries. Extended networks of suppliers and partners enable system integrators to deliver the highly complex systems and products their customers demand (Davies & Hobday, 2005). PBFs must maintain strong network connections in the pursuit of product developments. Network connections are a necessary by-product of the division of labour that is spread across many specialist firms that house the complex knowledge that comprise CoPS (Brusoni, 2005). These network relationships do not only supply technology. Increasingly, the complex nature of nested products requires integration, operation and maintenance services from suppliers. Such expanded contracts are commonly sold alongside CoPS like trains, flight simulators, aircraft engines, mobile phone networks and IT systems (Brusoni, 2005; Cova & Salle, 2007; Davies et al., 2007; Gann & Dodgson, 2010). Thus, network relationships help bring new products to fruition, help to integrate them into larger systems, operate them, and even maintain them, in close working relationships with the customers that bleed across firm boundaries.

The view of networking in CoPS literature is most often considered at the system integrator level (Brusoni et al., 2001; Davies & Hobday, 2005). Lost in these discussions are the autonomous attributes of lower tier firms (those working for system integrators, and the firms that in turn supply to them). It can be argued that this lack of attention is an oversight because lower tier firms also exhibit similar networking capabilities relative to innovation in order to integrate components and subsystems as well. These lower tier PBFs also have vested interests in maintaining robust networks to ‘create new knowledge from external networks and linkages, extend such knowledge to value creating activities and modify such knowledge to address the changing market conditions’ (Salunke et al., 2011, p. 1256). PBFs across the project-based productive maintain knowledge flows and thus enduring network connections that extend vertically to their suppliers and customers, and horizontally to other entities like external R&D laboratories (Gann & Salter, 2000; Hobday et al., 2005).

Some additional examples from the general project literature also help illustrate the need for networking to support innovation. Pauget and Wald (2013) describe a networking capability (relational competence) that exists across many tiers of a French hospital construction project network defining it as ‘ability to purposefully build, maintain and develop relations’ that contribute to information exchange and promote coordination in projects (p. 201). Pauget and Wald (2013) argue that particularly well-connected firms are in a position in the network to play the role of mediator to promote change and particularly promote innovation. In a stratified sample of Dutch industrial firms, Berghman et al. (2006) reveal that network competencies are strongly correlated with delivering customer value that they partially define in terms of new products. The network competencies they cite reflect the ability of firms to draw upon the innovation potential of the network connections, and also the inbound stimulus that these network connections provide for innovation purposes (Berghman et al., 2006). Similarly, Ritter and Gemünden (2003) argue that German mechanical and electrical engineering companies' 'network competence'—the ability to maintain and exploit inter-organisational relationships—is a strong predictor of product innovation success.

The social capital literature also helps to elaborate why such network connections would promote innovation specifically. Network partners allow detailed information exchanges that contribute to innovative performance (Uzzi, 1997), because they enable the trust-based sharing of tacit information which is important to novel product innovation development (Ahuja, 2000). Strong network relationships even serve an important role in helping the focal firm recognise the value of new information for the purposes of innovation, helping them to see potentials through the benefit of the complementary knowledge resident in network partners (Ahuja, 2000; Rost, 2011). Beyond this complementary nature of network ties, Hagedoorn and Duysters (2002) argue that 'quasi-redundant' ties, when similar types of network ties are maintained by the focal firm, can increase learning, help the firm develop new capabilities, and lead to overall higher innovative performance.

Overall, it is highly likely that networking is an important capability for PBFs. The development of CoPS-related novel products would require collaboration with suppliers, customers, and other network partners both to develop the innovation, and help to ensure its (albeit limited) diffusion. The importance of network partners for innovation is magnified by the increasingly blurred lines between products and services as customers increasingly buy both the technology and integration, operation and maintenance support from their suppliers (Davies et al., 2007; Gann & Dodgson, 2010; Gann & Salter, 2000). Thus, PBFs need to maintain strong connections in order to be successful knowledge integrators, and in particular to deliver novel products.

What networking capabilities look like

In CoPS-like environments, innovative firms maintain external networks consisting of inter-organisational connections to support industry projects and specifically to develop innovations (Gann & Salter, 2000; Hobday et al., 2005; Salunke et al., 2011). Firms with networking capability are broadly aware of the innovation activities of others in the network, particularly with regard to their own suppliers and customers (Martinsuo & Ahola, 2010;

Prencipe, 2000). This is especially true for any firm developing a complex product, for which the firm likely maintains in-house capabilities that match the subcontracted sub-systems and components, so that technological integration of these can ensue (Prencipe, 2000). This has been referred to a technological breadth (Prencipe, 2000). Thus, the development of products requires firms to extend beyond their immediate boundaries and to actively participate in the technology development processes in conjunction with other firms in the network (Gann & Salter, 2000; Salunke et al., 2011). Firms with networking capability are adept at aligning their external relationships toward achieving collective technological outcomes that the industry demands (Gann & Salter, 2000).

2.3.2. Open innovation to resolve technological interdependence

PBFs are faced with the specific problem of accounting for technological interdependencies in the development of novel products. This includes both inbound and outbound activities. On the inbound, firms must deal with interfaces between components and sub-system technologies in order to integrate them into a final product. On the outbound, firms must resolve interfaces and inter-dependencies with other technologies in the industry.

Open innovation offers a lens to understand how inter-organisational knowledge flows support novel product innovations. Because of the extremely tacit nature of knowledge regarding the development of CoPS innovations (Gann & Salter, 2000; Hobday et al., 2005), it would seem most appropriate to engage with the non-pecuniary aspects of open innovation (Dahlander & Gann, 2010). In this regard, two aspects of open innovation—inbound *sourcing* and outbound *revealing*—may play particularly important roles in the innovation activities of PBFs. As opposed to the pecuniary open innovations that involve transactions of codified knowledge in the form of licences, patents and non-pecuniary forms of open innovation relate more to the tacit dimensions of knowledge sharing.

On the inbound, sourcing (the leveraging existing external sources of information for innovation purposes) is closely related to the concept of innovative search (Laursen & Salter, 2006; March, 1963). Broadly, innovative search can be considered search for knowledge that will support new product or service development. It derives from the behavioural theory of the firm (Cyert & March 1963) and later, evolutionary economics (Nelson & Winter 1982), which has made *search* a prominent theoretical explanation of how the innovation processes of firms unfold (Laursen, 2012). There are three classic types of search. *Problemistic search* is viewed as reaction to a specific problem relating to current performance expectations not being met (Greve, 2003, 2007; Levinthal & March, 1993). A simplistic example is a firm engages in search for a new product in response to declining sales. A second form of search is *slack search* and it is characterised as undirected (Greve, 2003). The prototypical example is 3M's policy that affords researchers a weekly time allotment for self-directed research. A third form of search is *institutional search*, prototypically represented by directed research and development (R&D) efforts (Greve, 2003). In terms of PBFs, and the resolution of technological inter-dependency problem, problemistic search is assumed to be most appropriate reflection of the concept of sourcing.

Broad search, which is the wide-ranging knowledge-seeking pattern (Laursen & Salter, 2006; Leiponen & Helfat, 2010), may serve specific roles for PBFs. First, large CoPS-like projects have inherent uncertainties stemming from the complex[6] interaction of the many interrelated subsystems (Baccarini, 1996; Nightingale, 2000; Williams, 1999) and numerous participant firms (Kardes et al., 2013; Perminova et al., 2008; Van Marrewijk et al., 2008). Interactions between these elements give rise to unforeseen events and problems that need to be resolved (Ahola and Davies, 2012; Atkinson et al., 2006; Davies and Frederiksen, 2010; Jaafari, 2001; Stinchcombe and Heimer, 1985). Such uncertainties may induce firms to adopt broad search patterns, because the resulting diversity of information increases the probability that a (combinatory) novel solution can be found to the problems arising from uncertain environments (Leiponen & Helfat, 2010). The theoretical argument is that extensive search affords firms' advantages by increasing the potential for combinatory innovations. This in turn can then be translated into new products, thereby obtaining competitive advantage over others in the market (Leiponen & Helfat, 2010).

Second, broad search may help to overcome learning challenges facing project-based industries. The episodic nature of projects causes learning feedback loops to break down between project teams and the parent organisation (Gann & Salter, 2000), hindering innovation-related knowledge flows across projects (Brady & Davies, 2004; Gann & Salter, 2000; Scarbrough et al., 2004). Consequently, knowledge tends to remain tacit instead of being centralised at the organisational level (Gann & Salter, 2000). The implication of this is that many project-based firms lack stable knowledge repositories. Similar knowledge-constrained environments are known to induce broad search strategies (Garriga et al., 2013; Keupp & Gassmann, 2009). For instance, Garriga et al. (2013) find that Spanish

[6] Simon's (1962) definition of a complex system is '…one made up of a large number of parts that interact in a nonsimple way. In such systems, the whole is more than the sum of the parts, not in an ultimate, metaphysical sense, but in the important pragmatic sense that, given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole (p. 468).'

manufacturing firms search broadly when knowledge is not abundant. Similarly Keupp and Gassmann (2009) find Swiss manufacturing firms with information shortages search broadly. Thus PBFs faced with a problem, who lack of a central repository for answers, may turn to broad search because this situation is analogous to an information-poor operating environment.

However, there are also two arguments that suggest narrow search is likely, related to the propensity of firms to search locally and the limited slack resources available to PBFs to engage in search. On the first point, broad search can perhaps suppress novelty, particularly in settings with low technological dynamism (Sidhu, Commandeur, & Volberda, 2007) that typifies many CoPS industries (Whitley, 2006). For instance, when a technological regime is stable, such as when a dominant design has established itself (like internal combustion engines the auto industry), benefits accrue to firms that create innovations related to that design. The value of very new information obtained by technologically distant search (that which is not directly related to internal combustion) is reduced in terms of near-term potential to create new products that are accepted by the market place (Henderson & Clark, 1990; Sidhu et al., 2007). This perspective is related to the concept of local search, which is the theory that firms faced with problems tend to search locally for information to solve the problems, meaning that the information that is sought is located in close proximity to current knowledge sets (Helfat, 1994; Levinthal & March, 1993). For instance, in the R&D activities of oil and gas activities, Helfat (1994) found evidence of very small changes over time and between firms. This is a reflection of the stability of the knowledge bases in the industry, and incremental adaptation of knowledge over time, and the close proximity of current R&D activities to past R&D efforts (i.e. path dependence). Additional empirical evidence from Dutch electrical and metal manufacturing also supports this position. A study shows that at high levels of technological dynamism, that search is a positive contributor to innovation outcomes (measured as per cent of sales from new products), but low dynamisms and extensive search results in fewer innovations (Sidhu et al., 2007). However, this does not mean that searching close to existing knowledge sets is bad for innovation necessary. On the contrary, the ability to derive new innovations may hinge on the existing capabilities of the firm coupled with the new information obtained from elsewhere (Cohen & Levinthal, 1990; Gatignon et al., 2002). This is because most learning is associative in nature and thus it makes sense that search occurs in close relation to existing knowledge sets (Wang, Rodan, Fruin, & Xu, 2014). The development of completely new solutions is not only in the domain the completely now, but is rather dependent upon the ability to arrive at new combinations of existing knowledge (Katilia & Ahuja, 2002; Schumpeter, 1934).

On the second point, PBFs might be resource-constrained and not engage in slack search (Keegan & Turner, 2002), and it is well known that search requires both managerial attention and staff resources (Laursen & Salter, 2006), and that cost constraints—something that all projects are limited by—may focus search strategies narrowly (Lampert & Semadeni, 2010).

In the outbound, non-pecuniary *revealing* refers to knowledge made public and shared freely with others without any immediate prospect of compensation or reward (Dahlander & Gann, 2010), a co-development strategy that is increasingly seen in a range of industries and sectors including semiconductors, software, information systems, chemical analysers (Harhoff, Henkel, & von Hippel, 2003; Henkel et al., 2013) and synthetic biotech (Henkel & Maurer, 2009). Henkel et al. (2013) argue that many other industries will also begin to reveal more about their innovation activities, too spurred by customers' demands for more tailored product development efforts. They argue that strong intellectual property regimes will underpin this shift, primarily because this allows firms to reveal the first place (ensuring that their IP will not be co-opted). They speculate that revealing will reduce the need for time consuming firm-by-firm intellectual property sharing agreements. However, in CoPS-like settings, strong IP regimes already exist (Whitley, 2006), such as in the global oil and gas industry (Noke et al., 2008; Perrons & Donnelly, 2012). Tailored, low-volume innovations specifically designed for customers are the primary organising principle of entire industries (Hobday, 1998). Thus, the necessary ingredients which Henkel et al. (2013) believe necessary to sustain a culture of revealing, appear to be in place in CoPS-like settings already.

It is argued that revealing may have two specific purposes for PBFs: first, to support their innovation development activities, and second, to aid in the diffusion. In terms of development, strong interdependencies between firms and the systems they produce may require revealing during the design phases to ensure that the eventual systems and subsystems interfaces align, and that their innovations can be integrated into the larger system of production (Henkel & Baldwin, 2010). Indeed, it is well known that CoPS design processes are both very iterative and characterised by design feedback loops between the various project members for these very reasons (Miller & Lessard, 2000; Nightingale, 2000).

In terms of diffusion, revealing is thought to be an important method to draw interest from potential adopters (Harhoff et al., 2003). Although CoPS-related novel products have a more limited and well-defined market, revealing may still play an important role in persuading individual customers to integrate innovations into their larger systems (Gil et al., 2012; Henkel & Baldwin, 2010). In CoPS settings in particular, it appears necessary to reveal significant detail of novel innovations in order to convince project sponsors of their value and to give consideration toward implementing it (Gil et al., 2012). In many construction networks, the high levels of interdependencies between firms serves to slow diffusion of novel products, particularly if these innovations relate to commonly used systems that many different firms use to coordinate effort (Taylor et al., 2006). This is because innovations that affect common systems would require many interdependent firms to adopt the innovation (nearly) simultaneously. This causes trepidation in the adoption of very novel products, because if the rest do not adopt as well, then the focal firm will be out of step with the rest of the network, and there may be problems in coordination and project execution. A study of the US building construction industry showed that 3D design software was slow to diffuse and suggests that intensive communication of the benefits of the innovation is required to spur more simultaneous adoption (Taylor et al., 2006).

2.3.3. Structural embeddedness to understand enduring relationships

To address the problem of enduring relationships, the idea of structural embeddedness—the connections between firms—is used. However, the definitions and measurement of embeddedness requires some treatment before they can be applied to PBFs. The social capital literature clearly defines embeddedness, splitting it into two types: structural and relational (Rowley et al., 2000). Relational embeddedness refers to the strength of ties between actors based on attributes like trust (Rowley et al., 2000). Structural embeddedness refers to the structural patterns of the inter-organisational network that is comprised in the recurring patterns of interactions between firms (Jones et al., 1997; Jones & Lichtenstein, 2008). Uzzi (1997) argues that structural embeddedness is the architecture of the network relationships and its effect on the collaboration between economic actors. In terms of how inter-organisational relationships might impact the ability of PBFs to deliver novel innovations, a focus on structural embeddedness is pursued in this thesis for many reasons not requiring further mention.

Measuring structural embeddedness for PBFs is not straightforward. In social capital theory, there are many standardised measures of structural embeddedness relating to the actual structure of the network of relationships between firms (Borgatti, 2005) [7]. For instance,

[7] Formal measures include closeness centrality (essentially how far the firm is from the rest of the firms in the network) network centrality (how many times the firm directly brokers between two firms) or betweenness centrality (how many times the firm represents the shortest between two firms) (Borgatti, 2005).

a firm's network density can be calculated by the number of ties (e.g., peer firm alliances) maintained by a firm divided by all possible ties (Gilsing, Nooteboom, Vanhaverbeke, Duysters, & van den Oord, 2008). With regard to embeddedness in temporary organising, definitions and measures are less developed. Jones and Lichtenstein (2008) base theirs on the social capital literature to define structural embeddedness as the mutually shared (third party) connections that exist between project actors. Their argument is that in sufficiently complex project environments, like construction, repetitive interactions will increase the chances of firms having mutual third party contacts (Jones et al., 1997; Jones & Lichtenstein, 2008). However, this formal definition of embeddedness has received scant empirical attention. Bakker et al., (2011) develop a measure of embeddedness (implicitly structural) that was based on the idea of repeat collaboration between firms within particular projects. They measure embeddedness as the proportion of project participants that have prior direct ties. This study is limited since the ostensible goal was to understand the prevalence of repeat ties in a population, and they did not relate embeddedness to any outcome like innovation. More recent qualitative literature uses a single firm case study to defines functional and relational types of embeddedness rather loosely by relating them to technical capability and customer influence respectively (Ahola, Kujala, Laaksonen, & Aaltonen, 2013).

This lack of progress in defining and measuring structural embeddedness for PBFs points to a larger problem with formal measurement of embeddedness in project networks. That is, observing a large project network of relationships directly would be exceedingly difficult, because the scope and scale of these projects require thousands of firms. Consider the London Heathrow Terminal 5 expansion project, which required '80 first-, 500 second-, 2,000 third-, 5,000 fourth-, and 15,000 fifth-tier suppliers' (Davies et al., 2009 p. 109). Measuring embeddedness with existing tools proves to be a methodological challenge in such a domain. Because structural embeddedness cannot easily be observed in large project networks, a proxy measure is necessary.

One potential means to measure structural embeddedness is found in the economic geography literature where collaborations are used as a proxy to determine geographical embeddedness (Collinson & Wang, 2012; Love, Roper, & Hewitt-Dundas, 2010; Song et al., 2011). For instance, Love et al. (2010) analyse the relationship of local and international embeddedness with innovation within Irish firms. They explain embeddedness to be the presence of local and then non-local collaborations with suppliers, customers, competitors, universities, and labs/consultants. Similarly, Song et al. (2011) determine embeddedness by the number of relational ties that international R&D offices hold with local entities like universities and research institutions. Collinson and Wang (2012) use the number of external entities used for innovation purposes as a proxy measure of embeddedness. Measuring structural embeddedness based on collaborative ties to external actors appears to be one potentially feasible method to use in project networks.

This approach is cross-sectional, and that longitudinal study may be necessary to fully understand how collaborative relationships are enacted and maintained over time (Bakker, 2010; Manning & Sydow, 2011). Yet, if embeddedness is measured by proxy of formal collaborations, it arguably falls in line with Manning and Sydow's (2011) idea of 'connecting practices'. Connecting practices are 'recurrent activities that project partners engage in to link team and task properties of particular projects to past and potential future [project] collaborations. Connecting practices promote the pursuit of collaborative paths across project context and times of latency, yet they are also constrained by properties of established paths' *(*Manning and Sydow, 2011, *p. 1386).* Since formal collaborations represent formal commitments of the organisation, that may or may not be directly tied to projects, it is argued that formal collaborations represent a 'connecting practice'.

2.4. Chapter summary

First, this chapter established the conceptual background for the thesis. The study of CoPS-related novel product innovations is rooted in the innovation literature. The early study of innovation (e.g. Schumpeter, 1934) was connected to the study of innovation in the current day including, including its definitions and measures. The unique nature of innovation CoPS settings was reviewed, highlighting the distinct differences between it and mass-produced consumer goods, and in particular its nested and inter-organisational nature. This section defined CoPS-related novel product innovation and discussed its measurement.

Second, this chapter revealed gaps in the understanding of CoPS-related novel products. General gaps exist in the innovation literature, where product innovation studies are biased toward autonomous firms in manufacturing settings and in the CoPS literature which is focused on the lead system integrator. Neither perspective progresses a view about the patterns of activities that explain how PBFs introduce novel products into inter-dependent operating environments. Specific gaps include how PBFs capitalise on contingent opportunities that present themselves in the context of industry projects, how technological interdependencies are resolved, and the role of enduring relationships between firms relate to the introduction of CoPS-related novel products.

Third, this chapter outlined approaches to filling the three specific gaps. First, adaptive problem solving (an ad hoc problem solving approach) and networking (an ordinary capability) are posited as capabilities that help firms realise contingent opportunities for novel product innovation within projects contexts. Second, inbound and outbound non-pecuniary open innovation approaches can provide insight into how PBFs resolve technological interdependencies. These non-pecuniary flows are important because tacit knowledge is particularly important to innovation in project networks. Third, structural embeddedness with suppliers and customers are thought to be particularly important to innovation processes in PBFs. This section reviewed how these might impact novel product innovation in particular, and means to measure embeddedness by using cross-sectional data rather than measuring actual ties in a network.

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CHAPTER 3: RESEARCH METHODS PART I

This is the first of two methods chapters. This chapter provides an overview of the research theoretical perspectives, research approach, and methods. Chapter 4, *Research Methods Part II,* provides the details of the empirical methods including the specific survey design, operationalisation of the dependent and independent variables, model specification, and tests on the suitability of the underlying data to support the statistical interrogation methods.

The current chapter is organised as follows: First, the research design section states the conceptual approach, which is rooted in the concept project-based productive networks. It identifies a suitable research setting, establishes the sample frame, and details the data collection process and response rates. It also introduces the survey methods used on this sample frame, including details on the origin of the survey instrument, the approach taken to augment this instrument for this particular research setting, and the ethics that govern collection. Second, the methods used to interrogate the models and test the hypotheses are introduced. A third section concludes the chapter.

3.1. Research design

This section first discusses the research design in three parts. First, the idea of project-based productive networks is rehashed, which highlights the cross-section of firms necessary to explain how innovations are produced in CoPS-like settings (Gann & Salter, 2000). Second, the research setting is introduced, which is the Australian oil and gas industry. Third, the sample frame, details of the collection campaigns and response rates are shown by year. Fourth, the survey method is discussed, including the origin of the instrument and the method to tailor it to the specifics of the oil and gas industry. Fifth, ethical procedures that govern the data collection and protection are discussed.

3.1.1. Conceptual approach

The central concern of this thesis is to understand how PBFs, participating directly and indirectly in large and complex projects, inter-relate with each other to develop innovations. To restate the research question, it is: *What factors facilitate PBFs' ability to introduce novel product innovations in environments where interdependent firms deliver complex system-level outcomes?* To reiterate, PBFs are defined herein are those with primary business activities that are in support of the conduct of industry projects including supplying products and services, conducting project tasks, or sponsoring industry projects. This definition derives from the notion that PBFs operate inside project networks, which are stable networks of roles, relationships, and knowledge flows that are termed 'project-based productive networks' (Gann & Salter, 2000, p. 959) These firms operate in conjunction with each other to produce innovations (refer to the discussion in Section 1.1.2, and Figure 2).

Capturing data on firms operating within these networks presents three related hurdles. The first hurdle is identifying the research setting: finding a suitable project-based industry. The second hurdle is identifying the sample frame: targeting a cross-section of PBFs in a project-based productive network. The third hurdle is methodological. An approach is needed for measuring innovation activities of project-based firms in such a systematic way as to yield a representative picture of the cross-section. Further, said methods must confer the ability to test relationships between the firm-level factors and innovation. Each of these hurdles and means to overcome them are discussed next in turn.

3.1.2. Research setting

The first hurdle, selecting a suitable project-based industry as a research setting, is overcome by selecting the oil and gas industry. The oil and gas industry has long been defined as one that relies heavily on inter-organisational project organising (Barlow, 2000; Bower et al., 1997; Stinchcombe & Heimer, 1985). It is a mature industry that exhibits segmentation comprised of many specialised firms that serve distinct roles (Acha & Cusmano, 2005). Therefore, the project network structure, in terms of firms' positions and roles, will be well-defined and semi-stable (Davies & Hobday, 2005; Jacobides, Knudsen, & Augier, 2006; Jacobides, 2005). The next sub sections introduce the research setting in more detail. First, a very brief primer on the global upstream oil and gas industry is provided, highlighting the similarities in its structure to that of Gann and Salter's (2000) definition of a project-based productive network. Second, the specific context of Australian upstream oil and gas is discussed for exhaustiveness based on a recent academic book chapter on the subject (Ford et al., 2014).

Upstream oil and gas industry

The upstream oil and gas industry is responsible for the exploration and production of petroleum resources. *Exploration* is the search for geologically stored oil or gas resources through seismic surveys and exploratory well drilling, and *production* involves all the steps necessary extract resources (Persaud et al., 2003). The latter includes the building, development, and operation of oil and gas production facilities, both onshore and offshore. The remainder of the industry is considered *downstream* and is responsible for the refinement and distribution of petroleum resources, and is not of concern for this thesis.

The upstream industry, with its origins in the 1860s, provides a good example of an industry that has built up a highly interdependent ecosystem of firms with varying levels of specialisation (Acha and Cusmano, 2005). These specialist firms work together in the conduct of industry projects, and interrelate to develop technological advances and to support the overall innovation process of the industry (Acha and Cusmano, 2005; Crabtree et al., 1997). Despite trends in the largest companies toward vertical integration, exploration, construction, and production still requires a great deal of subcontracting to access a range of specialised firms (Barlow, 2000; Perrons & Donnelly, 2012; Stinchcombe & Heimer, 1985).

The structure of the upstream industry can be parsed into three tiers, namely: operators, contractors, and suppliers (Bower et al., 1997; Crabtree et al., 1997). The industry tier structure aligns directly with project-based production networks that Gann and Salter (2000) discuss, and their terminology is placed alongside the industry terminology in Table 7.

Table 7 - Upstream oil and gas industry

Oil and gas terminology	Gann and Salter (2000) terminology	Examples of PBFs	Main business function(s)
Operators	Customers	BP, Chevron, Exxon-Mobil, Origin, Santos, Shell, TOTAL, Woodside	• Capabilities have long tried to explain novel product innovation propensity of firms (Collis, 1994; Teece et al., 1997). • Exploration for oil and gas resources • Licensing oil and gas rights from governments • Joint venture field development projects
'service firms' below this line			
Contractors	Project-based firms	Baker Hughes, Bechtel, Halliburton, Laing O'Rourke, Leighton, Schlumberger, Thiess, Transocean, Weatherford	• Engineering and construction • Drilling (on-shore, off-shore, deepwater) • Field operations • Logistics and maintenance • Procurement
Suppliers	Supply-network	3M, Airwell, BOC gas, Cameron, Dow, GE Energy, Honeywell, ThyssenKrupp	• Bulk materials / services supply (chemicals, coatings, filters, hardware, tubulars) • Specialised products (compressors, drilling rigs, engines, environmental control systems, gages, pumps, separation systems, turbines, well controls) • Specialised services (consulting, engineering, geosciences, inspection, training, off-shore welding, diving, seismic imaging, submersibles)

Adapted from Bower et al. (1997), Crabtree et al. (1997)

Oil and gas operators perform a coordinating function in the industry and assume ultimate responsibility for the development of oil and gas fields (Barlow, 2000; Bower et al., 1997; Crabtree et al., 1997). In the language of Gann and Salter (2000), operators are customers. Operators own the projects and may also serve important system integration functions (Acha & Cusmano, 2005). Examples of these firms include international oil companies such as Chevron, Conoco Philips, and Shell. These firms form joint ventures with each other and license mineral rights from governments to develop large natural gas and petroleum extraction projects (Barlow, 2000). Once completed, the operators garner revenues from the production and sale of the oil and gas resources.

Operators are heavily reliant upon two lower tiers of support called *contractors* and *suppliers*. The contractor and supplier tiers relate directly to Gann and Salter's (2000) terminology of *project-based firms* and *supply network*, respectively. In the oil and gas industry parlance, these bottom two tiers are often simply referred to collectively as *service firms* (Perrons & Donnelly, 2012).

The contractors are responsible for much of the direct work on resource development projects. In very large projects, infrastructure development is handled by global behemoths like Bechtel and Flour that manage the engineering, procurement, and construction (EPC) aspects of projects. The activities they undertake include the coordination of engineering with other construction firms to build facilities, collection pipelines, storage facilities, pre-processing facilities, and compressor stations to facilitate transmission in pipelines of long distances. Another subset of contractors is known as oil field services providers and includes the likes of Baker Hughes, Halliburton and Schlumberger. These firms are the bastions of technology in the upstream oil and gas industry. They supply products and services ranging from seismic exploration to consulting services. In essence, they provide both high-tech hardware and the know-how to operate it (Persaud et al., 2003).

The supplier tier consists of specialised goods and services firms, whose services operators and contractors buy, as either an outsourcing or augmenting strategy (Bower et al., 1997). These firms provide special equipment like engines, pumps, control systems, filters, pipelines, and other material inputs into the oil and gas projects. This level also includes highly specialised technology and consulting services that support industry projects in terms of specific functions, including, for example, underwater welding, diving and/or submersibles for offshore oil and gas platforms.

Australian oil and gas industry context

Australian oil and gas is a particularly intensive, project-based industry undergoing significant capital investment as outlined in Ford et al., (2014b) and repeated here. Recent years have seen soaring investment in natural gas resources in Australia (BCA, 2012). A mix of conventional and unconventional natural gas projects are at the heart of this expenditure with a majority of projects focused on exporting Liquefied Natural Gas (LNG) to Asia. Conventional gas projects include offshore gas field developments like Chevron's Gorgon project in Western Australia. Unconventional gas projects include Queensland's Coal Seam Gas projects (ABC, 2012), which will bring together distributed gas wells from across a vast geographic distance to parallel LNG processing plants on Curtis Island, Gladstone, Australia. Taken together, Australia has more than $US190b in LNG export projects under construction (Reuters, 2013), placing Australia on track to becoming the world's largest exporter of LNG by 2025 (OECD, 2012). A list of the major projects, expected to be completed by 2020, is provided in Table 8.

Table 8 - Expected Australian LNG projects to 2020

Projects under construction	Developer(s)	Capacity (mtpa)	Cost ($US billion)	Development type
Gorgon 1,2,3	Chevron	15.6	52	Conventional, off-shore
Queensland Curtis Island (QCLNG) 1, 2	BG Group (QGC)	8.5	20.4	Coal Seam Gas
Gladstone LNG (GLNG) 1, 2	Santos/ PETRONAS/ Total / KOGAS	7.8	18.5	Coal Seam Gas
Australia Pacific LNG (APLNG) 1, 2	Conoco Phillips / Origin	9	25.4	Coal Seam gas
Icthys 1, 2	Inpex / Total	8.4	34	Conventional, Offshore
Prelude FLNG*	Shell / KOGAS	3.6	12.6	Conventional, floating offshore
Wheatstone 1, 2	Chevron	8.9	29	Conventional, Offshore

Source: Reuters (2013)

Cost overruns in these projects have become commonplace in the Australian oil and gas industry, a phenomenon that also affects most multi-billion infrastructure 'megaprojects' around globe (Flyvbjerg, 2014). In 2012, Chevron announced a $9 billion cost overrun on its Gorgon gas project with the final cost now estimated to be $52 billion (MENA, 2012). This represents a 40 per cent increase on the original 2009 project budget in $US terms. In 2012, cost overruns from Chevron, Woodside, BG, Santos, and Exxon Mobil totalled $25 billion (Ker, 2012). This pattern continued into 2013 with the Conoco/Origin joint venture APLNG announcing a more modest seven per cent overrun of $US1.3 billion (Reuters, 2013). The BG group's QCLNG project has witnessed a $US5b overrun (Chambers, 2013).

The Australian oil and gas industry is at a crucial turning point. Another $150b in LNG investment hangs in the balance and depends on the capacity of the industry to generate competitive investment returns (Daley and MacDonald-Smith, 2013). Already, Woodside has shelved the Browse LNG project and is considering cheaper alternatives—including floating LNG technology—and Shell has raised doubts about the viability of its Arrow LNG project citing cost pressures (Kelly, 2013). Future projects that are at risk are shown in Table 9.

Table 9 - LNG projects at risk

Projects may be finalised in 2013+	Developer(s)	Capacity (mtpa)	Est. Start
Browse 1, 2, 3	Woodside	12	2018
Arrow 1,2 LNG	Shell / PetroChina	8	2017
Sunrise FLNG	Woodside	3.5	2018
Bonaparte FLNG	GDF Suez / Santos	9	2018
Expansions			
Gorgon 4, 5	Chevron	10	2018+
Pluto 2, 3, 4, 5	Woodside	4.3 each	2015+
Wheatstone	Chevron	16.1	?
Darwin 2	ConocoPhillips	3.5	?
Arrow LNG 3,4	Shell PetroChina	10	?
Queensland Curtis Island LNG 3	BG (QGC)	3.5	?
Australia Pacific LNG 3,4	Origin / ConocoPhillips	9	?

Source: Reuters (2013)

3.1.3. Sample frame and collection

The second hurdle to overcome is correctly identifying the sample frame, or the cross-section of project-based firms operating in a project-based productive network. This hurdle was overcome by collaboration with the premier industry trade group for Australian upstream oil and gas, the Australian Petroleum Production and Exploration Association's (APPEA). APPEA's membership makes an excellent sample frame because, according to their website, they are the 'peak national body representing Australia's oil and gas exploration and production industry' with hundreds of member firms (APPEA, 2012). They also claim that their membership accounts for an estimated 98 per cent of all firms in the oil and gas sector in Australia (APPEA, 2012). This establishes the group as a premier resource for accessing the project-based productive network that is Australian oil and gas.

The sample frames ultimately established for the research consisted of senior executives from firms operating in the Australian oil and gas industry. These sample frames were primarily established using though APPEA, and supplemented by one other trade group (discussed later). Two data collection efforts were conducted, in 2012 (Year 1) and in late 2013/early 2014 (Year 2). The approach to accessing/collecting data and the response rates for each year is discussed in turn next.

The Year 1 sample frame was developed using the APPEA membership. In 2012, the Chief Operating Officer (COO) of APPEA, Eastern Region, was asked support a research study on innovation in oil and gas. In a meeting attended by UQ Business School representatives, and oil and gas consultancy partners from the consulting firm Ernst & Young, the APPEA COO provided verbal support for the study and offered to supply the executive level membership list to UQ pending approval from the CEO. Subsequently, APPEA's Chief Executive Officer (CEO) sent an email communiqué to their membership making them aware of the study, also providing an opportunity to opt out of the research. Firms were then given approximately two weeks to opt out of the study. After two weeks APPEA provided a cleansed list of nearly 400 senior executive contacts to the UQ Business School. Requests to opt out after this point were directed to UQ research staff. Another opportunity to opt out was provided to the firm by the phone survey company at the time of collection. Out of nearly 400 firms on their full membership and associate membership list, 297 firms were identified as the frame as shown in Table 10. To arrive at this sample frame, the list was vetted to focus only on PBFs directly to industry projects, by removing ancillary firms. Thus, firms that do not directly participate in oil and gas production projects—including universities, legal firms and consultancies—were removed from the sample.

Collection of data was conducted by the Institute for Social Science Research (ISSR) at the University of Queensland. ISSR was contracted to conduct the survey, using a computer-assisted telephone interviewing (CATI) system. The survey was administered by phone to the senior executives of APPEA's membership over a period 38 calendars days, starting on 14 August 2012 and ending 21 September 2012. Upon initial contact with the respondents, the ISSR staff read an introductory message describing the intent of the survey and offering the firm yet another opportunity to opt out. Out of the 297 firms solicited, 80 responses were received. This resulted in a 27 per cent response rate. This rate is close to the average response rates when targeting top management (Baruch, 1999).

Table 10 - Sample split for Year 1

	Response		Sample frame		Overall response rate
	N	split (%)	N	split (%)	(%)
Operators	25	31	94	32	27
Service	55	69	203	68	27
Totals	80	100	297	100	27

A call list error meant that 11 firms were removed prior to analysis as they were not directly tied to industry projects. This ultimately left 69 firms for analysis purposes, as summarised in Table 11. Even with the elimination of the 11 firms, the sample obtained was not significantly different from initial sample frame. A chi-square test of the difference between the sample frame and the sample obtained between operators and service firms did not yield a significant difference at the $p < .05$ level (χ^2=0.35, *df* =1, *ns*).

Table 11 - Revised sample split Year 1

	Response		Sample frame		Overall response rate
	N	split (%)	N	split (%)	(%)
Operators	25	36	94	32	27
Service	44	64	203	68	22
Totals	69	100	297	100	23

The Year 2 sample frame again targeted executives of firms operating in the Australian oil and gas industry, this time supported by two major industry groups; APPEA and the Toowoomba Surat Basin Enterprise (TSBE). In October 2013, the APPEA Chief Technical officer (CTO) and COO, Eastern Region, were asked to support the study. The CTO and COO agreed and subsequently the CEO sent an email indicating the survey was taking place and offering the opportunity to opt out. After two weeks, APPEA provided their cleansed national membership list. The sample was culled to eliminate firms that were only tangential to the productive function of the upstream oil and gas industry. This yielded a sample frame of 84 operators and 179 service firms. An additional trade group, the Toowoomba Surat Basin Enterprise (TSBE), was also targeted specifically to compliment the APPEA sample by including small and medium enterprise (SME) businesses and construction firms, which TSBE represents in Queensland, Australia. This industry group represents nearly 200 firms with wide-ranging specialties, many that directly participate in the supply chain of the upstream oil and gas industry. In November 2013, this author asked the Chief Executive Officer (CEO) of TSBE if their members would be willing to participate in the study. The CEO agreed, and TSBE's Marketing Manager emailed the membership offering firms the opportunity to opt out. After two weeks, TSBE supplied a list of over 100 firms that did not opt out. The sample was culled to eliminate firms not likely to directly participate in—or support—oil and gas projects. This procedure resulted in the identification of four operators and 82 service firms, the latter comprised of over 50 construction firms. The combined APPEA and TSBE groups together constitute the year two sample frame of 349 firms shown in Table 12.

Table 12 - Sample split for Year 2

	Response		Sample frame		Overall response rate
	N	split (%)	N	split (%)	(%)
Operators	33	32	88	25	38
Service	71	68	261	75	27
Totals	104	100	349	100	30

To collect the data in Year 2, the firm Colmar-Brunton was contracted to complete a phone-based CATI survey on this sample frame. Upon reaching each of the respondents, the Colmar-Brunton staff read a preamble that stated the intent of the survey and offered another chance to opt out. This data-collection campaign was launched on 25 November 2013 and closed on 12 February 2014. The total duration of the campaign was 79 days, inclusive of a two-week holiday stoppage. The overall response rate was 30 per cent. A chi-square test of the difference between the sample frame and the sample obtained (in terms of the operator – service firm split) did not yield a significant difference at the $p < .05$ level (χ^2=1.2, *df* =1, *ns*).

The entire combined sample frame response rates for Year 1 and Year 2 are shown in Table 13. A chi-square test of the difference between the frame and the obtained, between operators and service firms, does not yield a significant difference at the $p < .05$ level (χ^2 =1.786, *df* =1, *ns*).

Table 13 - Year 1 and Year 2 combined sample response

	Response		Sample Frame		Overall Response rate
	N	split (%)	N	split (%)	(%)
Operators	58	34	182	28	32
Service	115	66	464	72	25
Totals	173	100	646	100	27

3.1.4. Survey method

The third hurdle was obtaining consistent, representative cross-sectional data on firm-level innovation, conducive to analysis and comparison with the body of innovation studies.

To overcome this hurdle, a well-regarded innovation survey instrument was used. This made consistent the data collected from the cross-section of firms, and promoted comparison with the body of innovation literature. The specific survey used in the current research originates from Cambridge University and its Centre for Business Research (CBR) (Cosh et al., 2012). According to the CBR website, the centre was established in 1994 and has a growing global reputation in many areas including innovation research (Cambridge Centre for Business Research, n.d.). The content of the instrument has been well-tested, having been heavily used in CBR research conducted in the UK (Cosh and Hughes, 2007, 2003, 2000; Cosh et al., 2012). The Cambridge survey instrument follows a long tradition of innovation surveys that follow The Organisation for Economic Co-operation and Development's (OECD) Oslo manual (2005) guidelines. Oslo-type surveys are directed at the firm-level of analysis (Tether & Tajar, 2008). They directly assesses individual attributes of the firm including performance, finances, competitive situation, collaboration activities and innovation (Cosh & Hughes, 2009; Tether & Tajar, 2008). OECD-compliant surveys are used in many national level innovation surveys, and have become the basis of a significant amount of well-regarded innovation research (e.g. Cosh and Hughes, 2009; Grimpe and Sofka, 2009; Köhler et al., 2012; Leiponen and Helfat, 2010; Sofka and Grimpe, 2010).

The OECD's (2005) Oslo manual establishes standard categories and definitions for different types of innovation, and sets out measures for establishing degree of novelty, which the CBR instrument also adopts. Therefore, the decision to focus on the introduction of novel product innovation, for instance, is supported by a clear definition that has been consistently used in OECD-like innovation surveys for over a decade. This supports the interpretability of the research findings. Similarly, common constructs can be developed from the CBR instrument. For instance, the instrument collects data on sources of innovation information closely mirroring what is used in the UK community innovation surveys, which is the basis of Laursen and Salter's (2006) construct of search breadth. Search breadth measured how widely firms look for information to support their innovation processes. Therefore, the use of common definitions and variables in the CBR instrument allows the results of this thesis to be easily interpreted by other innovation researchers, and also specifically provides results that are comparable with prior studies.

Survey augmentation

The CBR survey instrument was slightly adapted to meet the needs of the research setting. The remainder of this section covers the general approach taken to modify and validate changes to the instrument, while specific changes are covered in Chapter 4.

Alteration of the survey instrument was in collaboration with industry experts. Changes were conducted at two different times, corresponding with the two collection efforts. Year 1 survey edits were undertaken between 2 June 2012 and 10 July 2012. During this time, the survey instrument was iteratively modified through close collaboration with four senior practice leaders at Ernst & Young Australia (three partners and one director). This effort resulted in new measurement items that captured nuances of innovation and collaboration relevant to the upstream oil and gas industry. This revised survey was then presented to the Chief Operating Officer (COO) of the Australian Petroleum Production and Exploration Association (APPEA), Eastern Region, who presented additional changes and suggestions. Following these changes, senior executives from two major oil and gas firms in Brisbane, Australia reviewed the survey instrument in July and again in August 2012. This resulted in the removal and clarification of several items. The survey was subsequently soft-tested with a lower priority subset of the industry sample to work out any remaining issues with the survey instrument, in August 2012. This process helped to streamline additions to the survey and ensure their viability for use with the sample. The Year 2 survey required fewer changes, and mostly focused on removing questions that were left unanswered or deemed confusing during Year 1. The instrument was modified from 20 September 20 2013 to 14 November 2013. The modifications were undertaken through iterative consultation with two Advisory Partners, one of whom is the Oceania Oil & Gas Advisory Leader, at the consulting firm Ernst & Young.

Ethics

The collection and analysis of data followed strict ethical procedures as outlined by the UQ business school. The research uses secondary data collected under ethical clearance #2009001621. Primary ethical concerns relate to informed consent and to privacy. With regard to informed consent, a three-step process was followed to approach firms. First, the industry trade groups contacted their membership to inform them of the study and its purpose, allowing approximately two weeks for firms to opt out of the phone survey. Second, subsequent opt-out requests were handled by this author. Third, the CATI phone survey interviewers in both years read lengthy preambles to respondents, describing the purpose of the survey and providing another clear opportunity to opt out of the study. With regard to privacy, all data were analysed in de-identified form, meaning that database entries were cleansed of any identifying information including respondent names, phone numbers, titles, company names and any other type of data that would be necessary to make an association or inference from the data to a real firm or its management. Further, the resulting analytical findings are not attributable to individual firms or persons. Analyses are based solely on exploration of numerical data and the relationships between in order to uncover correlations and relationships.

3.2. Analysis methods

This section covers the statistical procedures used to elucidate the relationships between various independent variables and novel product innovation across the three studies: Capabilities, Open Innovation, and Structural Embeddedness). This section first introduces these statistical procedures, starting with the choice of logistic regression. Second, non-parametric tests are presented. Third, approaches for mediation analysis are discussed.

3.2.1. Logistic regression

Logistic regression predicts placement of a firm into one of two outcome categories, typically yes and no condition encoded as a 1 (yes) or 0 (no) (which is the dependent variable), based on the information provided by various predictors (independent variables) in the models (Field, 2009). Logistic regression is aligned well with the central research question, which focuses on the factors that help support the introduction of novel product innovations for PBFs, an outcome that can be dichotomised as yes (1), no (0).

Logistic regression uses maximum likelihood estimation to produce a predictive model assigning an effect size (log-odds ratios) to each predictor. These odds ratios represent each independent variable's contribution toward achieving the outcome (novel product innovation). Thus, odds ratios have intuitive interpretation similar to ordinary least squares regression (OLS): one unit increase in the predictor results in an increased or decreased likelihood that outcome will be achieved, and that increase (or decrease) is equal to the odds ratio. For example, consider a simple model that contains only one predictor; namely, the total number of collaborations a firm has. Assume the dependent variable is novel product innovation encoded as yes (1), no (0). Assume the odds ration associated with collaboration is three, and this finding is significant at traditional levels. This would mean that each time the firm adds a collaborator, the odds of introducing a novel product innovation increase by three.

Another benefit of odds is that they can meaningfully be doubled, whereas probabilities above 50 per cent cannot. Probabilities and odds have a simple relationship.

Odds (O) are the probability (P) of an event over the probability of non-event as summarised in Equation 1. Table 14 shows some common conversions.

Equation 1 - Relationship between odds ($\boldsymbol{o}$) and probabilities ($\boldsymbol{p}$)

$$\boldsymbol{o = \frac{p}{(1-p)}\ and\ p = \frac{o}{(1+o)}}$$

Table 14 - Sample probabilities and odds conversions

Probability	Odds
0.10	0.11
0.30	0.43
0.50	1.00
0.70	2.33
0.90	9.00
0.95	19.00
0.98	49.00

3.2.2. Non-parametric tests

Dichotomous and count data are not normally distributed due to the relatively high number of zero values, which affect regression outcomes, and are considered to be non-parametric (Greene, 1997). The variables used in this thesis all fall into this category of being non-parametric. All three studies contained in this thesis use the same dependent variable, the dichotomous presence of novel product innovation, encoded yes (1), no (0). Independent variables include some Likert scale data, some count data and some categorical data. Although these data are not normally distributed, their use is not an issue for logistic regression since it does not assume normality (Field, 2009). However, in the univariate analyses which test individual relationships between variables, for instance when testing differences between individual variables across two groups, non-parametric tests are necessary (Field, 2009).

Three non-parametric tests are used in this thesis: Spearman's Rho (r_s) correlation coefficient, Mann-Whitney (U) test of means and chi-square cross tabulations. First, Spearman's Rho is used as the non-parametric alternative to Pearson's correlation coefficient (Field, 2009). It is used because Pearson's correlation requires interval or ratio level data, and most data of the data employed are either count data or dichotomous. Thus, all variables for each model are assessed using Spearman's Rho bivariate correlations prior to logistic regression.

Second, the Mann-Whitney *U* test of means is used when comparing a continuous or count variable to a dichotomous variable, or a comparing a continuous or count variable across two groups. The Mann-Whitney *U* is a non-parametric test that is based on mean rank scores (Field, 2009). When comparing a measure across two groups (for instance, number of collaborations against early (0) and late (1) responder groups), all scores (in this case, the number of collaborations) are assigned a rank (1, 2, 3…) in ascending order. The rank scores are added and placed into the original groups from which they came (early/late). The highest sum of ranks is the *U* score, and results are reported in the following form (statistical median of the variable (m), rank score (U), Z statistic (Z), significance level, estimated effect size (*r*)). The effect size is calculated by dividing the Z statistic by the square root of the sample size (n) (Field, 2009). If the result of the Mann-Whitney test is significant, the groups are significantly different. In this example, if the late group had the higher score and the result was significant, this would mean the late responders have more collaborations and the strength of this difference would be conveyed by the estimated effect size *r*.

Third, when comparing two dichotomous variables, cross-tabulations with the Fisher exact test are used (which finds the exact probability of the chi-square statistic), which is employed to overcome problems with small sample sizes (Field, 2009). Exact tests are used herein to test for non-response bias of the dependent variables, since the dependent variables (novel product innovation: no (0), yes (1)) and the groups (early (0), late (1) responders) are both dichotomous. If the test is significant, the result can be reported as an odds ratio. An odds ratio is created by dividing the odds of an event (lateness) occurring in group A (novel product innovators), by the odds of it (lateness) occurring in group B (non-innovators). Finally, the Mann-Whitney test and cross-tabulations are not just used to test for biases, but are also in limited cases to probe further into the results of the models, or to explore alternative explanations.

3.2.3. Mediation

To conduct the moderation analyses, two approaches were taken. In Study 1, a plug-in for SPSS called *Process* (Hayes, 2013) was used. The process tool harnesses the power of bootstrapping to establish confidence intervals for the indirect effect of mediating hypotheses. The tool reports confidence at 95 per cent intervals for the variables. The *process* tool only works with moderators that are not dichotomous. Therefore, the tool could not be used in Study 2, where R&D mediator is dichotomous.

For the models that have dichotomous mediators, the approach suggested by Baron and Kenny (1986) was followed. In each case, three individual logistic regressions were estimated, including controls as covariates. In each case: (1) the independent variable was regressed upon the dependent variable (path c); (2) the independent variable was regressed upon the mediator (path *a*); and (3) the mediator (path *b*) and independent variable (path *c'*) regressed simultaneously upon the dependent variable (see Figure 4) (Lichtenthaler & Ernst, 2007).

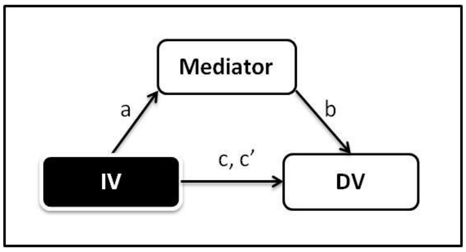

Figure 4 - Baron and Kenny (B-K) framework

In models using the B-K framework, a mediating effect is considered present when paths *a* and *b* are jointly significant. This joint test of significance minimises the chances of Type I error in small samples (MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002). To conduct the joint significance tests, the coefficients from each of the three logistic regressions were translated into comparable forms, and a Sobel test was conducted, to establish the significance of the indirect effect (Fujita & Han, 2009; Herr, n.d.; Mackinnon & Dwyer, 1993). Via both methods, standardised indirect effects are reported. This value is derived by dividing the product of paths *a* and *b* by the standard error of the dependent variable (Field, 2013).

3.3. Conclusion

First, this chapter outlined the ontological perspective of realism, and the epistemological stance of positivism, which govern the conduct of the research and the interpretation of its findings. Second, the research design was discussed, including the concept of PBFs that operate inside project networks, the selection of an appropriate research setting which is the upstream oil and gas, the establishment Australian oil and gas sample frame, the collection approach and results, and a high level introduction of the survey method. Third, the analytical methods to support the interrogation of the data were introduced. The next chapter—Chapter 4, *Research Methods Part II*— provides the details of survey, dependent and independent variables, models, and statistical tests that prove the suitability of the underlying data for interrogation.

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CHAPTER 4: RESEARCH METHODS PART II

This chapter opens by providing the specific detail of the survey items that form the basis for the operationalisation of variables. Dependent variables, independent variables, and controls are presented along with their operationalisation and theoretical justification. Second, the models necessary to test specific hypotheses (to support the studies in Chapters 5, 6, and 7) are introduced. Since the study chapters contain the details of the hypotheses, their reasoning is not repeated in this chapter. Third, the univariate analyses are presented that justify the model structures and selection of variables therein. A fourth section concludes the chapter.

4.1. Survey design

This section discusses the development of the dependent, independent, and control variables. Included in this discussion are any theoretical justifications for changes made to the survey instrument.

4.1.1. Dependent variables

The dependent variables are directly sourced from the original Cambridge Business Research (CBR) survey instrument, which is a well-regarded and well-tested instrument (Cosh & Hughes, 2000, 2003, 2007; Freel, 2003). The survey complies with international innovation measures set by the OECD's Oslo Manual (2005) (see Chapter 3). The survey instrument includes a preamble that clearly defines innovation for the respondent, in line with other CBR research (Cosh & Hughes, 2009, p. 74). The innovation preamble in the current survey reads as follows:

> *In this section we would like you to tell us about your innovative activity. Please count innovation as occurring when a new or significantly improved manufactured product, or service product, is introduced to the market ('product innovation'), or when a new or significantly improved production, or delivery method, is used commercially ('process innovation'), and when changes in knowledge or skills, routines, competence, equipment, or engineering practices are required to develop or make the new product, or to introduce the new process. Please do not count as product innovation, changes which are purely aesthetic (such as changes in colour or decoration), or which simply involve product differentiation (that is minor design or presentation changes which differentiate the product while leaving it technically unchanged in construction or performance). The implementation of a quality standard is not innovation unless it is directly related to the introduction of technologically*

new, or significantly improved, products or processes.

After this preamble, the survey instrument asks, *'has your firm introduced any of the following: technology, service, or managerial innovations in the past 3 years?'* Respondents answered this question across six types of innovation: product, process, product delivery, service, service delivery, and managerial. Based on the specific definitions, six discrete types of innovation can be developed that are of a dichotomous yes (1), no (0) form, as shown in Table 15.

Table 15 - Innovation types and operationalisation

Type	Definition	Variable	Operationalisation
Product innovation	Technologically new or significantly improved physical product / technology	INNPROD	Dichotomised incidence yes (1), no (0)
Process innovation	Technologically new or significantly improved methods of producing a physical product / technology	INNPROC	Dichotomised incidence yes (1), no (0)
Product delivery innovation	Technological improvements in supply, storage or distribution systems for physical product / technology	INNDIST	Dichotomised incidence yes (1), no (0)
Service innovation	New or significantly improved 'service product'	INNSERV	Dichotomised incidence yes (1), no (0)
Service delivery innovation	New method to produce and deliver your 'service product'	INNSERVDIST	Dichotomised incidence yes (1), no (0)
Managerial innovation	New organisational/managerial processes or marketing methods	INNMKTMGT	Dichotomised incidence yes (1), no (0)

Firms were also asked if each of the six types of innovation were either 'new to the firm but not new to the industry', or 'new to the firm and to the industry'. This helps to establish the degree of novelty of the innovation. Novel innovations can be considered any of the six types that are new to the firm *and* new to the industry. Incremental innovations are considered new to the firm, but not to the industry (Köhler et al., 2012b).

Based on the questions about types and novelty, a number of innovation variables can be constructed. For example, a novel product innovation can be defined as a technologically new or significantly improved physical product/technology that is both new to the firm and new to the industry. A novel innovation (general) can be any of the above six types of innovation that are new to the firm and new to the industry. Table 16 lists a number of variables that can be constructed, and all are dichotomous yes (1), no (0). The dependent variable of interest is novel product innovation (NOVPROD). This is the dependent variable in each of the main models in each study thesis. To investigate alternative explanations, some of the other variables are also used.

Table 16 - Innovation degree of novelty and operationalisation

Degree	Definition	Variable	Operationalisation
Novel	Any of six types of innovation that were new to the firm and new to the industry	NOVEL	Dichotomised incidence yes (1), no (0)
Incremental	Any of six types of innovation that were new to the firm but not new to the industry	INCREMENTAL	Dichotomised incidence yes (1), no (0)
Novel product*	Technologically new or significantly improved physical product / technology that is new to the firm and new to the industry	NOVPROD	Dichotomised incidence yes (1), no (0)
Novel process	Technologically new or significantly improved methods of producing a physical product / technology that is new to the firm and new to the industry	NOVPROC	Dichotomised incidence yes (1), no (0)
Novel supply chain	Technological improvements in supply, storage or distribution systems for physical product / technology that is new to the firm and new to the industry	NOVDIST	Dichotomised incidence yes (1), no (0)
Novel Service	New or significantly improved 'service product' that is new to the firm and new to the industry	NOVSERV	Dichotomised incidence yes (1), no (0)
Novel service delivery	New method to produce and deliver your 'service product' that is new to the firm and new to the industry	NOVSERDIST	Dichotomised incidence yes (1), no (0)
Novel management / marketing	New organisational/managerial processes or marketing methods that is new to the firm and new to the industry	NOVMGTMKT	Dichotomised incidence yes (1), no (0)

*dependent variable of interest

4.1.2. Independent variables

This section describes the independent variables used in each study, including how they were derived. An overview of the independent variables is shown in Table 17.

Table 17 - Independent variables overview

Study	Ch.	Variables / Constructs	Theoretical bases	Construction
Capabilities	5	Adaptive problem solving (ADAPT) Networking (NETWORK)	Adaptive problem solving (Loch et al., 2006; Nightingale et al., 2011; Shenhar, 2001; Stinchcombe & Heimer, 1985) Networking (Jones et al., 1997; Jones & Lichtenstein, 2008; Sydow et al., 2004; Sydow & Staber, 2002; Uzzi, 1997)	Confirmatory Factor analysis of items from sourced from Likert scale answers about 'competitive differentiators'
Open innovation	6	Sourcing (SOURCE), Revealing (REVEAL)	Non-pecuniary open innovation (Dahlander & Gann, 2010) to support important tacit knowledge flows (Gann & Salter, 2000)	Development of simple indicators of non-pecuniary outbound revealing activities (Henkel et al., 2013). Use of innovative search breadth to measure non-pecuniary in-bound sourcing activities (Laursen & Salter, 2006)
Structural embeddedness	7	Supplier and customer structural embeddedness (SUPP, CUST) Supplier and customer over-embeddedness (SUPP2, CUST2)	Structural embeddedness supports inter-organisational coordination and innovation (Gann & Salter, 2000; Jones & Lichtenstein, 2008). Over-embeddedness has potential downsides to innovation (Uzzi, 1997).	Proxy measure developed by using the number of modes of collaborations per collaborator type and is based based on concept of geographic embeddedness (Collinson & Wang, 2012; Love et al., 2010; Song et al., 2011).

Capabilities

The development of capability variables are based on answers to the section of the survey that deals with self-reports of competitive advantage. That section of the survey asks: 'Based on the list below, how would you rate your competitive advantage?' and the ratings for several distinct items are captured on a Likert scale of 1 (not a competitive advantage) to 5 (key differentiator). Questions covered a range of typical bases for competitive advantage, such as marketing and promotion skills, cost advantages, and specialised expertise/product/service/technology. The nature of items reflects a first-order or ordinary capability perspective in that they are simple reflections of the static differences that managers perceive their firm has over the competition (Winter, 2003). From this list of questions, two theoretically devised and empirically validated constructs were produced using confirmatory factor analysis (CFA). These constructs are based on the project literature, and are termed networking (NETWORK) and adaptive problem-solving (ADAPTIVE) capabilities.

Adaptive capabilities

There are (arguably) three important aspects of adaptive problem solving to consider at the firm level and they are: innovative problem solving within projects, ability to adapt to changing and unexpected circumstances in projects, and documenting and transferring lessons learned across projects. It is argued that these three items reflect an adaptive problem-solving capability to deal with the dynamic nature of work, particularly the persistent levels of uncertainty that accompany complex, long-duration projects (Jaafari, 2001). Each is discussed next.

The first two items—'ability to adapt to changing and unexpected circumstances in projects' and 'innovative problem-solving within projects'—progress a contingency-based perspective. This perspective states that innovation is inherently an inter-organisational problem-solving activity with regard to CoPS and infrastructure projects (Ahern et al., 2013; Ahola & Davies, 2012; Davies, 2013; Loch et al., 2006; Nightingale, Brady, Baden-fuller, Hopkins, & Brady, 2011; Pich, Loch, & de Meyer, 2002; Söderlund, 2002; Stinchcombe & Heimer, 1985). The third factor—documenting and transferring lessons learned across projects'—represents the ability transfer lessons from the past to address current problems. Because of the discontinuous nature of projects (time limitations, separation from parent firms), such learning is often disrupted from the project, to the organisation, and subsequently across projects (Brady & Davies, 2004; Davies & Brady, 2000; Gann & Salter, 2000; Prencipe & Tell, 2001). Therefore, the third added item reflects a problem-solving heuristic that leverages historical lessons to address the idiosyncratic circumstances of current projects. The items that comprise the adaptive problem-solving construct are listed in Table 18.

Table 18 - Adaptive problem solving capability elements

Construct	Items	Label	Basis				
ADAPTIVE	Innovative problem-solving within projects	SOLVE	Contingent project management recognises that innovation and is inherently an inter-organisational problem solving activity (Ahern et al., 2013; Ahola & Davies, 2012; Davies, 2013; Loch et al., 2006; Nightingale et al., 2011; Pich et al., 2002; Söderlund, 2002; Stinchcombe & Heimer, 1985).				
	Ability to adapt to changing and unexpected circumstances in projects	ADAPT	Firms' ability in all stages of projects to identify and track key sources of uncertainty, allowing problems to addressed early before they become costly (Atkinson et al., 2006), and including the ability to recognise upside potential of risks (opportunities) (Jaafari, 2001; Perminova et al., 2008).				
	Documenting and transferring lessons learned across projects	TRANS	Transfer successful aspects of past projects, avoid pitfalls, and create efficiencies in future projects (Brady & Davies, 2004; Davies & Brady, 2000; Söderlund & Tell, 2011).				
Construct details	N	Items	Mean	SD	Cronbach's Alpha	Min	Max
	104	3	3.3	.937	.798	1	5

CFA was conducted on the elements described in Table 18. Without loss of generality, a constraint was imposed on two of the regression coefficients to achieve identification, namely ADAPT and SOLVE (for each variance was set to 1). The three regression coefficients for the effects of the latent variable on the observed variables achieve significance ($p < .001$) and therefore convergent validity is achieved. The fit indices are shown in Table 19. The construct chi-square is not significant, which is expected for models with less than 12 factors (Hair, Anderson, Tatham, & Black, 2010). The construct has a GFI of .993 and RMSEA of 0.39, which are within acceptable range (Hair et al., 2010). The adaptive capability construct with standardised regression coefficients is pictured in Figure 5.

Table 19 - Fit Indices of adaptive capability

χ2	p	GFI	RMSEA
1.158	.282	.993	.039

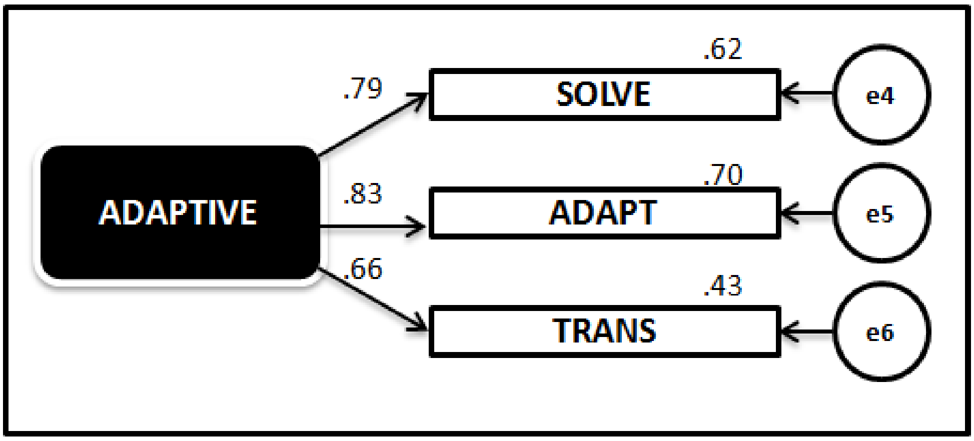

Figure 5 - Adaptive capability construct

Networking capabilities

A theorised networking construct is argued to contain three specific items. These are the 'range of expertise/products/services/technology', 'supply chain management and integration', and 'partner network and related arrangements'. First, the 'range of expertise/products/services/technology' aspect reflects the very critical 'systems integration' (Hobday et al. 2005) or 'knowledge integration' capabilities (Salunke et al., 2011) that underpin innovation in project networks. These skills are paramount for both system integrator firms and for the rest of the supply chain, because innovation requires firms to have an intimate understanding of the technological progress both upward toward customers and downward to suppliers, in order to integrate their offerings into the broader technology scheme of the industry (Gann & Salter, 2000; Prencipe, 2000). Second, 'supply chain management and integration' is demonstrative of firms' capacity to integrate knowledge specifically regarding their supply chain (Martinsuo & Ahola, 2010). In project networks, the vertical connections to customers and to suppliers plays a critical role in the development of innovation (Gann & Salter, 2000; Manley, 2008). Third, 'partner network and related arrangements' reflects firms' ability to maintain specific relationships in the network to support current activities and future opportunities as they arise. Specifically, firms manage multiple and sometimes redundant connections with other firms in order to quickly and easily augment capability across projects (Gann & Salter, 2000; Jones & Lichtenstein, 2008). In particular, having a latent network of potential collaborators promotes a combinatory approach to research development and commercialisation (Swan et al., 2007). The items comprising the NETWORK construct are shown in the Table 20.

Table 20 - Networking construct

Construct	Items	Label	Bases
NETWORK	Range of expertise / products / services / technology	Range_Expert	Reflects 'systems integration' (Hobday et al. 2005) or 'knowledge integration' capabilities (Salunke et al., 2011) that describes how firms integrate disparate knowledge from across their boundaries in the form of systems, subsystems, and services associated with their integration into larger and more complex product outcomes.
	Supply chain management and integration	SCM	Capacity to integrate knowledge specifically regarding supply chain partners (Martinsuo & Ahola, 2010).
	Partner network & related arrangements	NTWRK	Refers to the enduring network of inter-organisational relationships that supports both business projects, and innovation activities for firms operating in CoPS-like project-based industries (Gann & Salter, 2000; Hobday et al., 2005).

Construct details	N	Items	Mean	SD	Cronbach's Alpha	Min	Max
	104	3	2.99	.952	.741	1	5

Confirmatory Factor Analysis (CFA) was undertaken to establish the validity of these constructs on the most recent sample of 104 firms (see Figure 6). Without loss of generality, a constraint was imposed on two of the regression coefficients to achieve identification, namely Supply Chain Management (SCM) and Networking (NTWRK) (the variance of the construct was set to 1). All three of the regression coefficients for the effects of the latent variable on the observed variables achieve significance ($p < .001$) indicating convergent validity. The NETWORK construct is shown in Figure 6.

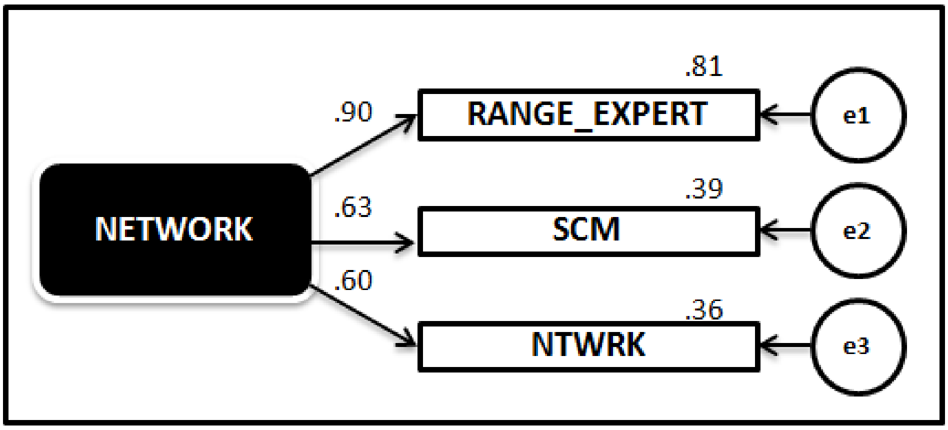

Figure 6 - Network capability construct

Target fit measures for assessing the CFA constructs are summarised in Table 21.

Table 21 - Fit indices and acceptable ranges for CFA

Abbreviation	Measure	Acceptable Range	Description	Reference
χ^2	Chi-square test statistic	*p* > .05	This is the probability that that the model fits the population perfectly. For less than 12 factors, insignificant p-values are expected.	(Hair et al., 2010)
GFI	Goodness-of-Fit Index	> 0.90	GFI is less than or equal to 1. A value of 1 indicates a perfect fit.	
RMSEA	Root Mean Square Error of Approximation	< .08	RMSEA of 0 indicates a perfect fit.	

SRMR not used because of biases associated with small numbers of factors per Hair et al., (2010)

Table 22 shows the fit measures for the NETWORK construct. The chi-square test statistic is not significant. The goodness of fit index (GFI) is .997. The RMSEA is .000. Based on these findings the model is accepted.

Table 22 - Fit indices of network capability

χ^2	p	GFI	RMSEA
.415	.520	.997	.000

Convergent and divergent validity

The next stage was to test for convergent and divergent validity (Jöreskog & Sörbom, 1996). For this next stage, a classic multi-factor model was created. The two latent variables in the model were correlated, and the six items of the first two models retained as indicators (Figure 7).

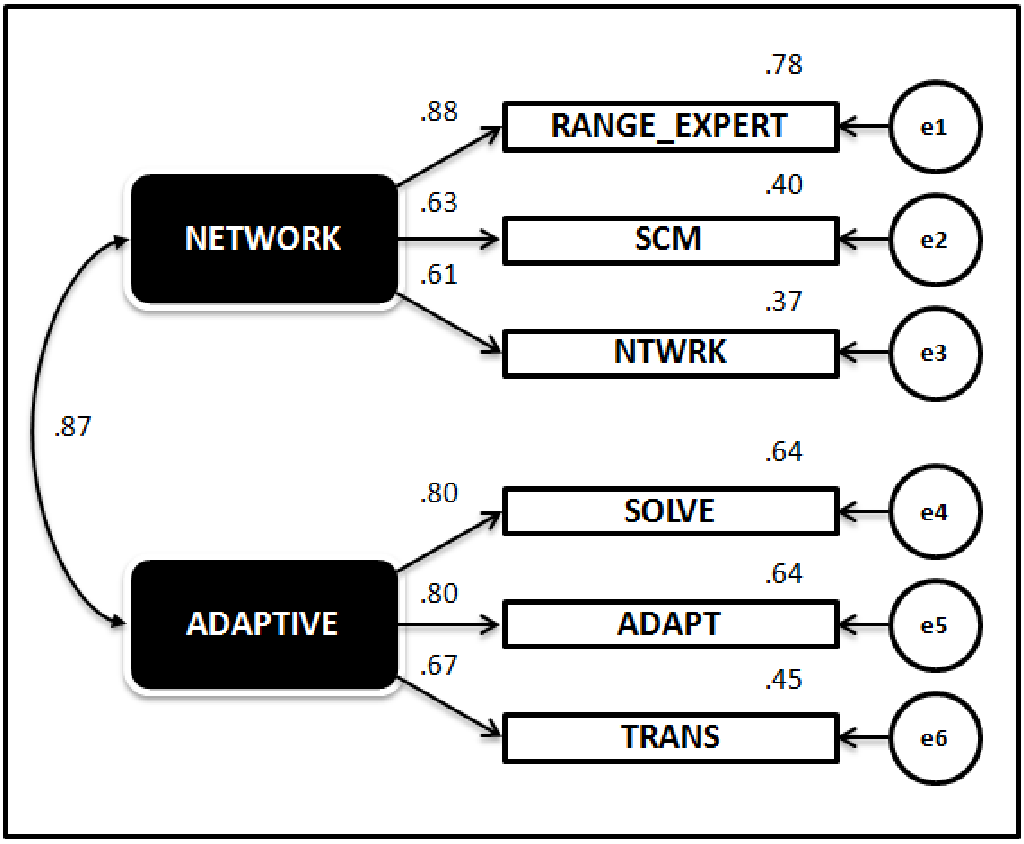

Figure 7 - Network and adaptive capabilities combined CFA diagram

This combined model achieved a chi-square of 11.43 and probability level of .325, a CMIN/DF of 1.14, a RMSEA of 0.037, and a GFI of .964 (Table 23). These results indicate acceptable fit of the nested model (Hair et al., 2010).

Table 23 - Fit indices for nested model

χ2	P	GFI	RMSEA
11.43	.325	.964	.037

Convergent validity is the degree to which two theoretically related constructs are indeed related, and convergent validity is indicated by a significant correlation between the two latent variables ($p < .001$). To further test this, the Average Variance Explained (AVE) for each of the factors should be above .5 (Hair et al., 2010). AVE was calculated by squaring the standardised factor loading scores for each item to obtain the VE, and the AVE is their average. By this measure, convergent validity is achieved as shown in Table 24.

Table 24 - Average Variance Explained and convergent validity

Construct	Item	Standardised factor loading	Variance Explained (VE)‡
NETWORK	RANGE	0.80	0.64
	SCM	0.80	0.64
	NTWK	0.67	0.45
		AVE	**0.58**
ADAPT	SOLVE	0.88	0.77
	ADAPT	0.63	0.40
	TRANS	0.61	0.37
		AVE	**0.51**

‡standard factor loading squared)

Discriminant validity is satisfied if the sub-scales are not the same construct. To test for divergent validity, three tests were conducted. First, the AVE values of the individual constructs should be greater than the squared correlation between them (Fornell & Larcker, 1981). The correlation between the two constructs in the nested model is .87, which squared is .76. This is indeed higher than the AVE of each of the factors, and this indicates a potential divergent validity problem. However, two other tests provide evidence that divergent validity is not an issue. In the second analysis, the correlations between the individual scale items and the constructs was tested, and this showed that the individual items loaded most strongly against their home construct (Verreynne, Meyer, & Liesch, 2014), which provides support to the discriminant validity of the model. Third, the nested model and a model that did not correlate the two factors were directly compared (Zait & Bertea, 2011), as shown Table 25. A chi-square test of differences between these two models was conducted and this difference was found to be significant ($p < .01$), which indicates that discriminant validity was achieved (Zait & Bertea, 2011). For this third test, bootstrapping was used to estimate the chi-square statistics to accommodate for any non-normal distribution of the factors, which would make the comparison of these chi-square test statistics problematic (IBM, 2011). The majority of the tests (2 of 3) indicate that discriminant validity is achieved for the nested model.

Table 25 - Two factor and single factor model fit indices

Model	$\chi2$	P	GFI	RMSEA
Nested model	11.4	.325	.964	.037
Uncorrelated model	84.3	.000	.836	.254

Open innovation

Dahlander and Gann (2010) organised the large body of literature on open innovation by reviewing a comprehensive list of articles found in the top management journals. The result of their work is presented as a two-by-two matrix, formed by the direction of knowledge flows and whether the activity is pecuniary or not. Dahlander and Gann's (2010) typology in Figure 8 reveals the resulting four types of openness: selling, acquiring, sourcing, and revealing. This thesis is concerned with non-pecuniary flows, which are discussed next.

	Inbound innovation	Outbound innovation
Pecuniary	Acquiring In-licensing, adopting or buying expertise or technology from external sources	Selling How firms protect, appropriate value from, and commercialise their intellectual property and technological artifacts
Non-pecuniary	Sourcing Leveraging existing external sources of information for innovation purposes	Revealing Sending information to the external environment selectively, in order to spur problem solving or aid in the diffusion of innovations

Adapted from Dahlander and Gann (2010)

Figure 8 - Open innovation typology

Sourcing is a non-pecuniary activity relating to surveying the external knowledge environment for technology and innovative ideas (Chesbrough & Crowther, 2006; Dahlander & Gann, 2010). There are many descriptions of this practice in the literature, an important one being *search breadth*, defined as the 'number of different sources of external knowledge that each firm draws upon in its innovative activities' (Laursen & Salter, 2006, p. 1204). A sourcing variable was developed using original questions from the survey instrument and is based on search breadth (Laursen & Salter, 2006). Search breadth in the current survey can be calculated on existing Likert scale responses about the use of 12 external sources of information used-for-innovation activities in the past three years. In following Laursen and Salter's (2006) search breadth operationalisation, breadth was calculated based on the number of sources used, which can range from 0 to 12. Counting toward search breadth is source rated 2 ('an insignificant source') and higher, because 1 on the Likert scale is 'not a source'. Breadth calculated for the current sample has a mean of 6.79 and a Cronbach's alpha of .806 based on 12 items. Laursen and Salter's (2006) sample had a mean of 7.21 for various manufacturing sectors, and a Cronbach's alpha coefficient of .93 based on 16 items. See

Table 26.

Table 26 - Open innovation variables

Construct	Operationalisation	Basis
SOURCE	Source is based on search breadth, and is the sum out of 12 external information sources cited as important to innovation activities in the past 3 years ranked 2 and higher on 5 point Likert scale (1 is 'not a source'). (M=6.8, SD=3.1, α=.806, 12 items). Can take the value of 0-12.	(Garriga et al., 2013; Laursen & Salter, 2006)
REVEAL	A sum of yes (1) no (0) answers indicating *open sharing* or *closed sharing*. Firms were asked 'Has your organization been involved in one or more of the following activities in the last three years'. *Open sharing* is 'Shared technical details openly to the industry to spur subsequent innovation or adoption of technology (e.g., any way real technical detail is shared externally but with no immediate direct monetary benefit)?' *Closed sharing* is: 'Shared technical information via confidentiality agreements in order to explore potential larger partnerships or licensing opportunities?' Can take the value of 0, 1, or 2.	(Dahlander & Gann, 2010; Harhoff et al., 2003; Henkel & Baldwin, 2010; Henkel & Maurer, 2009)

Revealing is the non-pecuniary form of outbound openness. The important aspect of revealing is the lack of immediate economic benefit from the revealing activity (Dahlander & Gann, 2010; Henkel & Baldwin, 2010). Revealing select details about innovations might serve two purposes. First, revealing might be necessary in the development process in order to ensure that novel products are suited to integrate into larger technological systems (Henkel & Baldwin, 2010). Second, revealing might spur interest in the adoption and diffusion of product innovations (Harhoff et al., 2003).

To capture revealing activities, the following questions were added to the Cambridge survey instrument: 'Shared technical information via confidentiality agreements in order to explore potential larger partnerships or licensing opportunities?' and 'Shared technical details openly to the industry to spur subsequent innovation or adoption of technology?' (Dahlander & Gann, 2010; Henkel & Baldwin, 2010). Revealing was operationalised by adding together the binary presence of either of these activities and thus can take the value of 0, 1, or 2.

Structural embeddedness

Structural embeddedness variables were created from a list of questions about nine different collaboration modes shown in Table 27. This list consists of seven collaboration modes that are original items from the survey instrument. Two additional modes were added in consultation with oil and gas experts at Ernst and Young. Of these, the first, 'streamlining the supply chain', reflects the inter-organisational nature of the oil and gas industry and the increasing reliance upon specialised contractors with increasingly global reach (Crabtree et al., 1997; Kardes et al., 2013; Perrons & Donnelly, 2012). The second, 'improving and sharing infrastructure (road/pipes/rails)', reflects the capital-intensive nature of the industry's megaprojects (Business Council of Australia, 2012; Flyvbjerg et al., 2003) and, in particular, the pipeline infrastructure necessary to support the collection, transport, and treatment of geographically distributed coal seam gas (ABC, 2012) .

Table 27 - Collaboration modes from survey

Collaboration mode	Source
Management and staff development	CBR
Gaining access to (or spread costs) of new equipment, technology or information sources	CBR
Purchasing jointly materials or inputs	CBR
Streamlining the supply chain	Ernst & Young
Outsourcing aspects of your business operations	CBR
Improving and sharing infrastructure (roads/pipes/rails)	Ernst & Young
Development of specialist services /products required by customers?	CBR
Sharing research and/or development activity	CBR
Involvement in collaborative R&D activities funded through grants	CBR

CBR = Question is native to Cambridge Business Research Survey Instrument
Ernst & Young = Added by oil and gas advisory consulting experts, see section 3.1.4

Firms were asked if they maintained any of the nine modes with five different collaborator types: suppliers, customers, higher education/research institutes, private research institutes/consultants, and firms in their line of business. All five collaborator types are native to the original survey instrument. Variables for each collaborator type (SUPP and CUST) are created by summing the number of collaboration modes that were indicated under each collaborator type.

This operationalisation is termed structural embeddedness, because it is assessed by adding the number of collaboration modes a firm engages with each individual collaborator type, a measure very similar to that used in the economic geography literature to measure geographical embeddedness (Collinson & Wang, 2012; Love et al., 2010; Song et al., 2011) (a richer description of the logic behind these variables is included in the theory section 2.3.3). In this case, the construct measures how broadly, or in how many different ways, firms are embedded *within* particular collaborator types. Since there are nine different collaboration modes in Table 27, each structural embeddedness variable can have a score from 0 to 9. The constructs show relatively high levels of internal consistency (Field, 2009; Hair et al., 2010) as measured by the Cronbach's alpha. Structural over-embeddedness refers to very deep embedded relationships. The quadratic (squared) customer (CUST2) and supplier embeddedness (SUPP2) terms were chosen to reflect this deeply and over-embedded state (see in Table 28).

Table 28 - Structural embeddedness constructs

Construct	Description	Cronbach's Alpha (9 items)
SUPP	Supplier embeddedness is the number of collaboration modes present with suppliers	.722
CUST	Customer embeddedness is the number of collaboration modes present with customers	.762
SUPP2	Supplier embeddedness squared reflects deeply embedded relationships called 'supplier over-embeddedness'	
CUST2	Customer embeddedness squared reflects deeply embedded relationships called 'customer over-embeddedness'	

Customer and supplier structural embeddedness (and over-embeddedness) is comprised of many different modes that differ in scope, ranging from grant-based R&D to managerial training. The rationale for grouping such dissimilar activities into a single construct is close collaborative relationships of all types that might—depending on the circumstances and timing—represent opportunities for innovation (Acha et al., 2005). This is because PBFs invest in innovations in an episodic manner, basing these investments on the specific circumstances of individual projects and the opportunities that these projects represent (Acha et al., 2005). Firms most often undertake the innovation activity to meet the industry's project needs (Barlow, 2000; Blindenbach-Driessen & Van Den Ende, 2010; Davies et al., 2009; Gann & Salter, 2000; Gann, 2000; Gil & Tether, 2011) and strive to integrate innovation activities into the technology trajectory of the industry (Gann & Salter, 2000; Gann, 2000). Thus, any enduring collaborative relationships in this type of environment—regardless of the original impetus—might serve as a locus for innovation activity depending on the circumstances. In such an environment, separating collaborations that are explicitly developmental from those that are potentially developmental would be illogical.

4.1.3. Control variables

A control for R&D is used in the model's order to control for the firm's relative investment in innovation capabilities, which support the ability to recognise the value of external information, to assimilate it, and to leverage it to commercial ends (Cohen & Levinthal, 1990). Here, the construct is a simple dichotomised variable indicating the presence of R&D (encoded 1) or not (encoded 0) (Moilanen, Østbye, & Woll, 2014). Missing data did not allow an R&D intensity control to be calculated; however, there the binary indication of R&D activities reflects an ongoing commitment to developing important skills, relative to capturing and using external knowledge in the innovation process (Moilanen et al., 2014). A control for firm size (LOGSIZE) is based on the number of full-time staff and contractors employed by the firm. The variable is log-transformed in order to make it linear, which is a requirement of the logistic regression (Field, 2009). The variable POC (Panel Ordinal Control) is used to control for the year of sampling, and is used in some models where panel data are used. It is tri-level and encodes Year 1 (1), Year 2 (2), and panel firm (3). See Table 29.

Table 29 - Control variables

Construct	Variable name	Operationalisation	Basis
R&D	R&D	Dummy variable operationalised by the presence of any research and development activities; yes (1), no (0).	(Cohen & Levinthal, 1990; Moilanen et al., 2014)
Firm Size	LOGSIZE	The Log base 10 transformation of the number full time equivalent employees (includes contract and internal staff counts).	(Cosh et al., 2012)
Panel ordinal control	POC	Takes the value of 1 if a year one, 2 if year two, 3 if panel firm (answered in both years). Used as a control in models where panel data is used but cross-sectional analysis is conducted (Chapter 6 and Chapter 7).	

4.2. Model specification

This section previews the specific logistic regression models that are tested in each study (Chapters 5, 6, and 7).

4.2.1. Capabilities

Five models test the hypothesised relationships (developed in Chapter 5), shown here in Table 30. The dependent variable is novel product innovation (NOVPROD). Independent variables include networking (NETWORK) and adaptive problem-solving (ADAPTIVE) capabilities. Controls included in each model are R&D and the natural log of firm size measured by number of staff (LOGSIZE). The subset of data used for these capability models are firms from Year 2 of the survey (for details of the sample subset used see section 4.3.1).

Model 1 tests for the effect of controls on the dependent variable novel product innovation. Model 2 tests adaptive problem solving capability in isolation. Model 3 tests networking capability in isolation. Model 4 tests both capabilities in tandem. Model 5 is a moderating hypothesis, that adaptive problem solving operates through networking capabilities to novel product innovation. Table 29 indicates the variables used to test this mediating relationship.

Table 30 - Capability regression models

NOVPROD	Model	1	2	3	4	5‡
	Hypothesis	Controls	H1	H2	H1,H2	H3
IV	NETWORK			x	x	x
	ADAPTIVE		x		x	x
Controls	R&D	x	x	x	x	x
	LOGSIZE	x	x	x	x	x

‡Model is depicted graphically in the text

4.2.2. Open innovation

Six logistic models are used to test the open innovation hypotheses (developed in Chapter 6), shown here in Table 31. The dependent variable, novel product innovation is denoted as NOVPROD. Independent variables include outbound activities revealing (REVEAL) and inbound activities sourcing (SOURCE). Controls include R&D and size (LOGSIZE) and POC, used to control for repeat firms present in the sample (this is fully explained in section 4.3.1). The subsample used to test the models consists of 121 innovating firms from both years. Model 1 tests the direct relationship between the controls and novel product innovation. Model 2 tests sourcing in isolation. Model 3 tests revealing in isolation. Model 4 tests both independent variables in tandem. Models 5 and 6 indicate the variables used to test the mediating relationships. Model 6 tests whether the relationship between sourcing and novel product innovation is mediated by R&D. Model 7 tests whether the relationship between revealing and novel product innovation is mediated by R&D.

Table 31 - Open innovation regression models

NOVPROD	Model	1	2	3	4	5‡	6‡
	Hypothesis	Controls	H1	H2	H1, H2	H1a	H2a
IVs	SOURCE		x		x	x	
	REVEAL			x	x		x
Controls	R&D	x	x	x	x	x	x
	POC	x	x	x	x	x	x
	LOGSIZE	x	x	x	x	x	x

‡Models results are shown diagrammatically

4.2.3. Structural embeddedness

The models necessary to test the hypotheses developed in Chapter 7 are shown in

Table 32. The dependent of novel product innovation is denoted as NOVPROD. Independent variables include supplier embeddedness (SUPP), customer embeddedness (CUST), and quadratic (squared) versions of each of these variables that represent over-embeddedness (SUPP2 and CUST2). Controls in the models are R&D, and LOGSIZE, and POC. The portion of the sample used to populate these models is non-panel firms from Year 1 and all firms from Year 2 (see section 4.3.1 for an explanation). Model 1 tests only the controls. Model 2 tests supplier, Model 3 tests customer, and Model 4 tests both types of embeddedness in tandem. Models 5, 6, and 7 respectively test supplier over-embeddedness, customer over-embeddedness, and both forms of over-embeddedness in tandem. Model 8 tests the moderating hypothesis that customer embeddedness may adversely impact the effect of supplier embeddedness on novel product innovation.

Table 32 - Embeddedness regression models

NOVPROD	Model	1	2	3	4	5	6	7	8
	Hypotheses	controls	H1	H2	H1, H2	H3	H4	H3, 4	H5
Independent variables	SUPP		x		x	x		x	x
	SUPP2					x		x	
	CUST			x	x		x	x	x
	CUST2						x	x	
	SUPPxCUST								x
Controls	R&D	x	x	x	x	x		x	x
	LOGSIZE	x	x	x	x	x		x	x
	POC	x	x	x	x	x		x	x

4.3. Univariate analyses

Typically the database would be analysed *en masse* to identify the suitability of the dataset for analysis. However, each individual study uses different variables and different portions of the sample. Study 1 uses Year 2 data, because data on its underlying constructs were only collected in that period. Studies 2 and 3 use data collected in both years, but study 2 narrows its focus on firms that have innovated, because these firms answered the open innovation questions that other firms were not asked. Therefore, even the variables that are shared across studies are still analysed in terms of each study's models.

This section outlines the univariate analysis tests and results that justify the suitability of the individual variables used in each study and each model, in three parts: meeting the assumptions of logistic regression (multi-collinearity, linearity, and independence of errors), outliers and missing data, and testing of sample biases (selection bias, non-response bias, and common method bias).

4.3.1. Meeting the assumptions of logistic regression

It is important to note that logistic regression relaxes the assumption of normally distributed data (thus skewness and kurtosis are not an issue) (Field, 2009). However, there are three other specific assumptions of logistic regression that must be met: multi-collinearity, linearity, and independence of errors between cases (Field, 2009). Each is discussed next.

Multi-collinearity

The first assumption is that there is no multi-collinearity between predictor variables. Multi-collinearity is checked by performing linear regression using the same predictor and outcome variables and inspecting the collinearity diagnostics (Field, 2009). Multi-collinearity is assumed to be not a problem if the Variance Inflation Factors (VIF) are below 10 and on average not be much larger than 1 (Field, 2009). The tolerance measures should be above .2, or at worse .1, which would be a cause for major concern (Field, 2009). The eigen values of cross product matrix, and the associated variance proportions from each variable are also inspected to ascertain if significant portions of variance is shared between predictor variables (Field, 2009). However, some of these rules of thumb can be relaxed in models that contain interaction terms or quadratics (squared terms) because these terms will be correlated with their untransformed twins (Sun, Yin, & Wang, 2014). Multi-collinearity of this nature does not impact the p-values of the coefficients for interaction or quadratic term in such models (Sun et al., 2014).

No issues regarding multi-collinearity were found for any of the studies. The results for Study 1, Capabilities, shows reveals average VIFs near 1, and tolerance numbers above .9, which are well within range (Field, 2009). The results of Study 2, Open innovation, show that multi-collinearity is no cause for concern. In the full model, average VIF is well within range at an average1.09 and tolerance numbers are above .at .92 on average, well above the .2 level, which might indicate a concern (Field, 2009). In study 3, Structural embeddedness, there is also no cause for concern. Each model was checked individually. For instance, in Model 4, which includes customer and supplier embeddedness but does not contain interaction terms or quadratic terms, the average VIF is 1.38, which is close to recommended value (Field, 2009). In the individual quadratic models that test supplier and customer over-embeddedness, the VIFs for the base and quadratic predictors increase but are still well within the upper limit of 10. Even in the full Model 5, which includes supplier and customer embeddedness and over-embeddedness, the maximum VIF is less than 9. VIF is expected to be high in these models since the quadratic and the base terms are related, but this type of collinearity is not a concern in the regression analysis since it does not impact the regression coefficients (Sun et al., 2014). Finally, in the interaction model, the VIF of the interaction term reaches 4.7, which is still well below the limit, and the tolerance measures are well above the .2 limit of concern (Field, 2009).

Linearity

The second assumption of logistic regression is that a linear relationship exists between the predictors (specifically the log transformation or logit) and the dependent variable. The assumption of linearity applies only to the continuous variables because dichotomous variables already have a linear relationship with the dichotomous outcome variable (Field, 2009). Thus, linearity is not a concern for many of the variables used in the thesis as many are dichotomous.

Nonetheless, to test for nonlinear variables, the *linktest* command is invoked in Stata version 13 immediately after the *logit* routine (Chen, Ender, Mitchell, & Wells, 2014). The *linktest* command is predicated on the assumption that other significant predictors should not be found except by chance. To test for this, *linktest* rebuilds the original model using linear predicted value (_hat) (which should be significant if the model is correctly specified) and the linear predicted value squared (_hatsq). If the square term is significant, this indicates a specification error (Chen et al., 2014). If a specification error is found, it may indicate two things. First, it might indicate that alternative transformations of the predictors are necessary to achieve a linear relationship. A second reason for specification error is that that important variables have been omitted from the analysis, and therefore a linear relationship between the logits of the predictors and the dependent variable cannot be established (Chen et al., 2014).

No problems with linearity were found for any study. In the Capability study, the *linktest* command shows that linearity is achieved because in each model, the linear predicted was significant at $p < .05$ and its square was not (Chen et al., 2014). Similarly, the open innovation models yielded no significant findings using the *linktest* command in Stat version 13, because in all models the linear predicted value was highly significant at $p < .01$ and the square of the predicted value was not significant (Chen et al., 2014). The structural embeddedness models yielded no significant findings either. In each model the linear predicted value was highly significant at the $p < .05$ in most cases ($p < .1$ in one case), indicating a good model fit and a linear relationship between predictors. The square term of the predicted value (_yhat) was insignificant, indicating that no important variables had been omitted from the analysis (Chen et al., 2014).

Independence of errors

This brings us to the third and final assumption, which is that individual cases have independent errors (Field, 2009). If all firms are unrelated and distinct entries, then this assumption is met. However, panel data (the same case, measured in two different times) violate the independence assumption since cases are indeed related. The steps taken to deal with panel data are discussed next.

Data were initially collected at two points to facilitate longitudinal analysis. However, there was significant attrition and only 35 firms responded in both years. The size of the longitudinal sample severely limits the number of variables that can be included in statistical models (Tabachnick & Fidell, 2007). Therefore, any attempt to conduct longitudinal modelling was abandoned. Faced with too few data points to conduct serious longitudinal modelling, and the relatively modest sample size of just 173 firms collected over two years (see Chapter 3), steps were taken to retain as much data as possible.

Random effects logistic regression analysis was undertaken to ascertain whether data from firms collected in both years (i.e., the panel data) could be interrogated via normal cross-sectional logistic regression. Specifically, Stata version 13 was employed and the *xtlogit* routine used. The *xtlogit* routine ascertains independence of responses or the intra-class correlation of the panel firms (Rodriguez & Elo, 2003). Random effects modeling produces a test statistic *Rho*, which tests the null hypothesis that there is no intra-class correlation. If *Rho* is indistinguishable from zero, there is no intra-class correlation between the panel firms' responses in either year (Gutierrez, Carter, & Drukker, 2001). This means that the panel firm responses are independent of each other, and cross-sectional analysis of the data are appropriate (Sillito, 2012).

For Study 1 (Capabilities), Year 2 data were used and thus it contains no panel data. This is because the adaptive capability construct (which is central to the analysis) is comprised of items that were added to the Year 2 survey, and so it could not be calculated for Year 1 firms. Therefore, normal cross sectional analysis of the Year 2 (n=104) data were used, and because of this, the independence of errors assumption is met because the cases are distinct firm entities (Field, 2009).

For the open innovation study, the subsample consists of 121 firms (out of 173 collected over two years) that are innovators, because they were posed questions about open innovation, which form the independent variables. The innovating firms were comprised of

54 firms that only answered in 2012, 46 firms that only answered in 2013, and 21 firms that answered in both years. This subset of data was subjected to random effects logistic regression, using the *xtlogit* routine in Stata version 13. This produced a statistic *Rho* that is indistinguishable from zero, which meant that there was no apparent intra-class correlation (Gutierrez et al., 2001), and thus cross-sectional analysis of the data was appropriate (Sillito, 2012). Therefore, models developed for this chapter employ data from all 121 innovating firms and subject them to regular cross-sectional logistic regression in SPSS version 22. A control is added to the model variables called panel ordinal control (POC, see 4.1.3) to capture any additional variance from this approach. An alternative method to control intra-class correlation would have been to conduct a clustered standard errors analysis. However, comparisons of cross-sectional logits using the POC control variable, and clustered standard errors analysis (conducted in Stata v 13), yielded no appreciable differences in results. Thus, the prior approach is used and presented herein.

For the structural embeddedness study, the same random effects logistic regression approach was used to ascertain if there was any intra-class correlation in the sample, and whether the entire sample could be used. This analysis revealed no intra-class correlation of the panel firms and, therefore, the entire sample of 173 are assessed using cross-sectional logistic regression analysis (Sillito, 2012) in SPSS version 22. Similar to the open innovation study, the POC control variable is used in the models as an extra safeguard.

4.3.2. Outliers and missing data

To identify outliers, standardised residuals for each model are inspected for outliers outside of two standard deviations of the mean (Field, 2009). As a rule of thumb, outliers should be kept—particularly if they represent less than five per cent of the total sample (Field, 2009). Others have argued that outliers should be retained, unless there is compelling evidence that they are not a true representation of the population (Hair et al., 2010). The inspection of outliers used herein follows the five per cent rule of thumb, but also inspects the outliers with regard to their influence on the model. To measure the undue influence, the Cook’s distance measures the effect of specific cases on the overall model to ensure that they are less than one (Field, 2009). If these criteria were met, the outliers were kept in the models.

None of the models have problems with outliers. The capability models were inspected for standardised residuals outside of two standard deviations from the mean, and were found to be just above the cut off of 5 per cent, at between 6 and 8 per cent. However, none of the cases appeared to be causing undue influence on the models based on the Cook's distance. Hence the outliers were kept in the models, since they likely represent plausible cases in the population (Hair et al., 2010). Inspection of the open innovation standardised residuals revealed that only 2 per cent of the cases were outliers in the open innovation models—well below the 5 per cent rule of thumb—and none of the cases were shown to exhibit undue influence in the models based on the Cook's distance. Therefore, the outliers that were identified were kept (Hair et al., 2010). For the structural embeddedness study, inspection of the standardised residuals for all models showed that outliers outside of 2 standard deviations amounted to less than 5 per cent, except for two models that had 6 and 7 per cent outliers (Field, 2009). Further inspection of undue influence yielded no findings with regard to the Cook's distance measures (Field, 2009). Hence, the outliers were retained because there was no compelling evidence that the outliers do not reflect the actual population (Hair et al., 2010).

There are no missing data for the variables used in the thesis (there were of course missing data in some other areas of the survey instrument). This lack of missing data is a benefit of the phone survey method which increases complete responses, and the helpful and engaged executive membership of the trade group.

4.3.3. Sample bias testing

Preventative measures were taken, and some post-hoc tests conducted, to ensure that the sample does not contain biases. This section reviews common method bias, selection bias, and non-response bias.

Selection bias

Selection bias occurs when the sample does not reflect the actual characteristics of the population. The sample obtained versus the sample frames do not differ significantly (a chi-square exact test of differences was not significant) for either year of the survey shown in Section 3.1.3. No prior studies have been conducted on Australian oil and gas using an approach similar to that contained herein; therefore, no direct comparison of the attributes of the sample to the population can be performed. However, the overall response rates of near 30 per cent (Baruch, 1999) from a sample frame that represents 98 per cent of the upstream oil and gas production capacity of the industry (APPEA, 2013), coupled with the non-significant result of the chi-square difference test, provide compelling evidence that a representative of the actual population of upstream oil and gas firms in the Australian setting was obtained.

Non-response bias

Non-response bias occurs when those answering the survey differ significantly from those who did not. A *post-hoc* test was undertaken to test for selection bias, based on the theory that late responders exhibit characteristics similar to non-responders (Armstrong & Overton, 1977). To test for non-response bias, the sample of firms used in each model was split into early and late responder groups delineated by the halfway mark of each of the collection campaigns (de Villiers & van Staden, 2010). Difference testing between the two groups on the variables used in each model interests was conducted. For continuous variables, the Mann-Whitney non-parametric test (*U)* of means was used. For dichotomous variables, cross-tabulation chi-square (χ^2) tests were used to see if significant differences exist between groups. Significant differences found in either method would indicate selection bias.

Testing for non-response bias yields no cause for concern in any of the models. In the capability models, the Mann-Whitney (*U*) test of means showed no significant differences between early and late responders for either capability variable: NETWORK (median = 3, *U* = 1200.5, *Z* = -.54, *ns*, *r*= -.05); ADAPT (median = 3.33, *U* = 1151.5, *Z* = -.87, *ns*, *r*= -.08). Similarly, chi-square tests for dichotomous dependent variables yielded no significant findings (exact test, 2-tailed). There are no significant findings for the control variables either. With regard to the open innovation models, there is no reason to believe there is non-response bias. No significant difference exists for the dependent variable NOVPROD (χ^2 = .016, *ns* (two-tailed)). Similarly, there were no findings for the independent variables tested via either Mann-Whitney *U* or by chi-square cross tabulation (if dichotomous): SOURCE (median = 7, *U* = 1463.5, *Z* = -1.8, *ns*, *r* = -.16); REVEAL (median = 1, *U* = 1758, *Z* = -.25, *ns*, *r* = -.02); No findings were found with regard to controls: RD (χ^2 = .329, *ns* (two-tailed)); LOGSIZE (median = 1.9, *U* = 3231.5, *Z* = -1.4, *ns*, *r*= -.12). Finally, tests for non-response bias yielded no significant findings for any of the variables used in embeddedness models. The dependent variable NOVPROD shows no bias (χ^2 = .001, *ns*). Independent variables show no bias: SUPP (median = 0, *U* = 3590.5, *Z* = -.31, *ns*); CUST (median = 0, *U* = 3330, *Z* = -1.4, *ns*); SUPPCUST (median = 0, *U* = 3561.5, *Z* = -.527, *ns*). There were no findings relative to the control variables, LOGSIZE (median = 1.69, *U* = 3231.5, *Z* = -1.35, *ns*) or R&D (χ^2 = .01, *ns*). Therefore, there is no reason to believe that there is non-response bias in these models.

Common method bias

Common method bias (CMB) is a concern because the data are obtained from a single-respondent survey (Podsakoff et al., 2003). Two steps were taken with regard to CMB—one to minimise it and a second to measure its presence. First, methodological separation was undertaken in the design of the survey (Podsakoff et al., 2003). The methodological separation consists of employing a combination of question types that were dispersed across the survey. The question types included fill-in responses (e.g., in the collection of the firm age), yes/no answers (e.g., types of innovation), multiple choice (e.g., innovation novelty), and Likert scale responses (e.g., Likert ranking of firm capabilities on a scale of 1 to 5). Each sub-section of the survey (basic information, collaboration, and innovation) employed at least two of these methods in different combinations. Second, a statistical method known as the Harman single factor test was conducted on all variables contained in each model (Leiponen and Helfat, 2010; Podsakoff and Organ, 1986). This test uses exploratory factor analysis (EFA) to identify whether a single factor might account for a significant portion of overall variance that may represent a latent factor or alternative explanation behind the model (Chang & Eden, 2010). Principal component analysis with both unrotated and Varimax rotations in SPSS Version 22 were used for this purpose. The resulting factor loadings were compared and contrasted in terms of total variance they explain, and particular attention is paid to whether dependent and independent variables load onto the same factors.

Tests for common method bias yielded no cause for concern in any of the studies. In the capability models, both the Varimax rotated and unrotated solutions yielded two factors, and the first factor accounted for less than 39 per cent of the variance. The dependent variable did not load on the either factor above the .5 cut off. The independent variables (networking and adaptive capabilities) loaded almost on the first factor, and the controls on the second. Considering the test is very conservative with few variables (Podsakoff & Organ, 1986) and two distinct factors still emerged there is no cause for concern that the models are coloured by CMB.

In the open innovation models, all variables were entered into the principle component factor analysis, and both the unrotated and Varimax rotated solutions consistently yielded three factors. The first factor explained less than 27 per cent of the variance in both cases. The dependent variable—novel product innovation—loaded on the first factor but very close to the .5 cut-off, and only in the unrotated solution. Novel product innovation loaded more strongly on the second factor in the Varimax solution, but this factor only explained 20 per cent of the variance. The independent variables and the dependent variables did not load on the same factor in either the Varimax rotated or unrotated solutions. The independent variables did load on the third factor together in the Varimax rotated solution, but this factor only explains18 of the variance, and revealing was very close to the .5 cut off. Since the dependent variables and the independent variables do not load strongly on any one factor, do not load together strongly in general, and no single factor explains any substantial amount of total variance, it appears by the standards of this test that CMB is not a substantial problem (Leiponen & Helfat, 2010).

In the embeddedness models, for both the un-rotated and Varimax rotated solutions two factors were derived and the first factor accounted for around 40 per cent of the variance. The first factor contained the independent collaboration variables (SUPP and CUST), while the dependent variable (NOVPROD) loaded evenly across both factors, and the R&D control variable loaded clearly onto the second factor. Although the explained variance on the first factor may sound high at 40 per cent, there are three reasons why it is not a concern: First, the SUPP and CUST variables explain much of the variance simply because they are they are count variables and display the most variability in the variables tested, whereas the other variables are dichotomous and do not have much variability. Second, the parsimonious nature of the models means that there are few variables being tested and thus the test is very conservative (Podsakoff & Organ, 1986). Despite this parsimony, two distinct factors still emerged. Third, and perhaps most importantly, dependent variable NOVPROD loaded evenly across both factors and both were near the cut-off point of consideration of 0.5, hence it is not closely tied to the collaborations independent variables, nor the R&D control. Hence there appears to be no single alternative factor that explains the relationships between these variables.

4.4. Conclusion

This chapter revealed the details of the variables and models used to test the hypothesised relationships of this thesis. The derivation of the dependent, independent, and control variables was explained. The specific empirical model constructions were described. The univariate analysis of the variables used in each model was conducted to show that the models are appropriately constructed, and no issues were found that could not be explained sufficiently. Finally, the variables were subjected to tests to reveal any biases in the data, and none were found. The next chapter—Chapter 5, *Capabilities*— develops the hypothesised relationships between novel product innovations and two capability constructs.

CHAPTER 5: STUDY ONE - CAPABILITIES

While it is recognised that project based organising—and PBFs in particular—are important to the development of novel technological product systems (Hobday, 2000), PBFs operate in an environment where the opportunities for innovation are contingent upon the projects that are conducted in the industry (Acha et al., 2005; Barlow, 2000; Stinchcombe & Heimer, 1985; Whitley, 2002). In general, the opportunities for developing novel innovations are considered to be rare in these settings, in part due to stable customer sets desiring certainty in technology, and in part due to the high level of technological interdependencies between specialist firms, both which serve to make significant technological changes difficult (Whitley, 2002). The result of stability between partners and interdependencies is pressure on firms to deliver incremental innovations that lie close to existing technological trajectories, because novelty portents reputational damage to the firm for being an unreliable technology partner (Whitley, 2002). Further, when opportunities for innovation do arise, they are often unforseen—related to the resolution of technological problems stemming from many sources of uncertainty that typify the design and implementation processes of CoPS (Nightingale et al., 2011; Nightingale, 2000; Stinchcombe & Heimer, 1985). This means that when opportunities to innovate in novel ways arise, they cannot be foreseen by PBFs, and they must adjust in reaction to these opportunities to innovate (Acha et al., 2005).

Capabilities have long been a popular lens to view the phenomenon of new product development in firms (Collis, 1994; Leonard-barton, 1992; Teece et al., 1997). In the strategic management literature, the discussion on capabilities is derived from theoretical and empirical data on high-velocity environments characterised by tumultuous technological upheaval, shifting market dynamics, and an ever-changing customer base—such as the software, computing, and biotechnology industries (Eisenhardt & Martin, 2000). Dynamic capabilities are considered to be the means by which competitive firms change their resource base and routines to consistently deliver new products and services into these marketplaces (Teece et al., 1997). Thus, dynamic capabilities are purposeful investments to promote change within the organisation (Winter, 2003). Dynamic capabilities are high-level routines that are the change agents that modify lower-level ‘ordinary capabilities’ (Hine et al., 2013; Winter, 2003). Ordinary capabilities are the normal means by which the firm makes a living, for instance by selling products or conducting projects.

However, in the low-velocity settings that PBFs operate in, the use of dynamic capabilities to drive change is called into question (Winter, 2003). Because opportunities for innovation are contingent upon the circumstances offered within the projects—and often these opportunities are related to emergent problems unknown ahead of time—it is far more likely that PBFs rely on ad hoc problem solving as a means to drive changes in their routines or resource bases (Winter, 2003). There are several reasons for this, including time constraints, costs, and applicability. First, in an environment where PBFs are continually constrained by timelines associated with the delivery of projects, there is often little time devoted the building of core ‘ordinary capabilities’ of the firm, let alone a high-level dynamic capability to drive change (Bayer & Gann, 2007). Second, in low-velocity settings, it would be costly to develop a dynamic capability where it would be used infrequently—and it would degrade over time—thus, ad hoc problem solving represents the most economical approach to driving change (Winter, 2003). Third, dynamic capabilities are specific investments to drive particular types of change and are potentially of little use in situations that were not anticipated (Winter, 2300). Thus, for PBFs, ad hoc problem solving provides a non-routine adaptive response to the needs at hand, which tracks well with the episodic and contingent nature of innovation facing PBFs (Acha et al., 2005). Hence, rather than relying on dynamic capabilities as the means to change the existing resource base of the firm to deliver value as in high-velocity settings, PBFs rely on ad hoc problem solving because of the contingent and episodic nature of innovation.

Due to the interdependent nature of innovation for PBFs, networking capabilities are also argued to play an important role in novel product innovation. Networking capabilities specifically relate to the ability to integrate disparate knowledge sets and to leverage partners and suppliers (Davies & Hobday, 2005). In the integration of knowledge, successfully innovating firms maintain knowledge of supplier and customer innovation activities, in order to understand how their own innovations fit into the larger systems (Brusoni, 2005; Gann & Salter, 2000). This knowledge extends beyond what the focal PBF ‘makes’ and has been referred to as technological breadth (Prencipe, 2000). In the leveraging of network partners, the ability to deliver a novel product requires complicit support from customers and suppliers in the projects, and also requires leveraging capabilities from network partners to meet project timelines in projects (Manley, 2008). The ability to leverage network partnerships in this way to deliver innovation is considered a core capability of the modern firm (Hobday et al., 2005). In this sense, networking is considered a necessary component of doing business in project networks where interdependent actors support a technology trajectory (Gann & Salter, 2000). In the arguments of Winter (2003), therefore, networking is an ordinary capability in the sense that it appears necessary at a fundamental level for PBFs to make a living in such an interdependent and innovation-focused industry setting (Hobday, 1998).

This thesis developed two capability constructs to reflect the above discussion points. First, to mirror ad hoc problem solving, a capability construct called *adaptive problem solving* was developed. This embodies the important capacity of PBFs to engage in innovative problem solving in the face of uncertainties accompanying complex engineering projects (Stinchcombe & Heimer, 1985). To reflect the enduring need to engage with network partners in the development of innovations (Gann & Salter, 2000), an ordinary capability construct called *networking* was also developed.

This chapter develops and tests specific hypotheses that speculate as to the relationship between these two capabilities and novel product innovation. The chapter has four parts. First, the hypothesis section presents hypothesised relationships between each capability and novel product innovation. The second section tests each model and presents the results. A third section discusses the findings. A fourth section summarises the chapter. A detailed summary and conclusion are reserved for Chapter 8.

5.1. Hypotheses

This section presents the hypotheses that describe the relationship between capabilities and novel product innovation. Each capability's direct relationship with novel product innovation is hypothesised separately in the first two subsections. A third subsection hypothesises that networking mediates the relationship between adaptive problem solving and novel product innovation.

5.1.1. Adaptive capabilities

Adaptive problem solving is a contingent response to circumstances confronting PBFs. Adaptive problem solving capabilities are argued to be important for PBFs in order to adapt and respond to changing circumstances and emergent events that typify the large inter-organisational projects in which they participate (Ahern et al., 2013; Ahola & Davies, 2012; Davies, 2013; Nightingale et al., 2011; Söderlund, 2002; Stinchcombe & Heimer, 1985).

On the one hand, the reactionary focus of adaptive problem solving might not portend novel outcomes. PBFs are not able to clearly foretell technological requirements because they only become apparent within the context of new projects (Acha et al., 2005; Acha, 2008) or problems that emerge during execution (Stinchcombe & Heimer, 1985). In the short term, this might lead to incremental solutions rather than novel solutions, in line with the incremental pace of technological change that characterises CoPS industries (Whitley, 2002). Customers and network partners look for reliable technology solutions, which are often well-tested in similar projects, and may demure from novel solutions (Keegan & Turner, 2002;

Manley, 2008). For instance, it is likely that firms will draw upon past experiences in their current projects, particularly those problem-solving experiences and solutions associated with similar problem sets (Acha et al., 2005; Nightingale, 2000). Relying on past experiences may provide an efficient way to address new problems, but may ultimately lead to developing incremental solutions rather than looking at the problem anew (Levinthal & March, 1993).

On the other hand, the longer timeframes associated with major projects that PBFs participate in might allow for more novel outcomes to come about, even if through a reactive problem-solving approach (Miller & Lessard, 2000) For instance, the problems that arise in complex projects can emerge from complex interactions between technologies, the environment, interactions between firms, regulations, and stakeholder pressures, all which can occur at any stage during the design and execution of major projects that can last up to ten years (Miller & Lessard, 2000; Nightingale, 2000; Shenhar & Dvir, 2007, 1996; Stinchcombe & Heimer, 1985). Over time, emergent problems from these interactions can shift the technology profiles of major projects (Miller & Lessard, 2000). These shifts represent significant opportunities for a range of products and process innovations to be developed through a reactive and coordinated response with the project team partners (Barlow, 2000; Davies et al., 2009; Stinchcombe & Heimer, 1985). The ability to recognise these problems as opportunities for innovation is a significant success factor in large and complex projects (Barlow, 2000; Jaafari, 2001; Perminova et al., 2008). To capitalise on these opportunities within project contexts, firms may reallocate resources toward developing new solutions, and even pursue commensurate investments in R&D if time allows (Acha et. al., 2005). From this longer-term perspective, the ability to draw on past experiences might not just lead to implementing old solutions, but could be used as building blocks to promote novelty or stepping stones to get there (Kogut & Zander, 1992).

Thus, in CoPS project settings with longer-term projects—where PBFS collectively solve challenges and problems that emerge throughout the design and execution—problem solving can support the development novel product outcomes. Given the time, PBFs can adapt and adjust to the changing circumstances (and even invest in R&D) to solve the particular problems posed by projects, all the while drawing on past experiences as a basis for improvement. Although these actions are non-routine, they can still result in changes to the organisation which allow the development novel product outcomes (Winter, 2003). Given the time, the novel outcomes can be negotiated into use by lobbying project owners (Gil et al., 2012), and accepted by the larger system of interdependent system of technology providers as part of a shift in technological trajectory (Gann & Salter, 2000). Alignment of PBFs toward the resolution of common problem sets over long durations helps explain how reactive adaptation can still promote novel outcomes (Hobday, 1998). Thus, PBFs exhibiting high levels of adaptive problem-solving capabilities will increase the probability of introducing novel product innovations, and the following hypothesis is progressed:

H1: Increasing levels of adaptive problem-solving capabilities will relate to novel product innovations.

5.1.2. Networking capabilities

In the development of innovations, PBFs draw upon specialist suppliers and network partners, arranging them into new combinations to deliver bespoke products to customers (Davies & Hobday, 2005). The need for network partnerships to support innovation stems from the need to integrate differentiated knowledge sets that reside in specialist firms (Brusoni et al., 2001; Hobday et al., 2005). This specialisation of knowledge derives from the inherent complexity of technology that stretches beyond the ability of any single firm to maintain all knowledge and capacity to produce CoPS (Brusoni, 2005). PBFs maintain knowledge of their network partners' capabilities, and leverage these capabilities to outsource components and subsystems, while simultaneously maintaining a working knowledge of the technology that is outsourced (Prencipe, 2000). These network partnerships can be considered complementary assets that are vital to the firm's strategic positioning and innovation capability (Teece, 1986). As a capability, this has been referred to as 'technological breadth' (Prencipe, 2000) underpins the ability to integrate the outsourced technological components into higher-level systems and products (Brusoni et al., 2001; Prencipe, 2000), and fit into the larger technological trajectory of the industry (Gann & Salter, 2000). Within individual projects, the success of innovations requires close coordination of network partners to help ensure that innovations meet project requirements and will be integrated into use (Gil et al., 2012; Manley, 2008). The early integration of specialist suppliers into new projects is likely to increase the innovativeness of the outcome (Martinsuo & Ahola, 2010). The reason that networking relationships are likely to be important to innovation potential is that they increase opportunities for learning, and they engender trust-based relationships, which form collaborative pathways toward innovation (Manning & Sydow, 2011). Such strong and collaborative network connections are important to support the tacit nature of knowledge that accompanies novel innovations (Jones et al., 1997). Strong networks are particularly important in the identification and assessment of the value of new information that could lead new innovations (Ahuja, 2000), particularly in terms of facilitating the commercialisation of such innovations (Rost, 2011).

That said, there are potential innovation downsides to networking, such as having too dense of an immediate network, which may limit the amount of new information a focal firm receives as well as its ability to leverage novel information from the network (Rost, 2011). But the networking capability described herein is not a structural attribute. Rather, it is capability to leverage network partners to support innovation, which for PBFs, appears to be very important for finding niches for new technologies and negotiating them into use in project settings (Manley, 2008; Pauget & Wald, 2013; Ritter & Gemünden, 2003; Salunke et al., 2011).

Thus, a networking capability is likely to be important for PBFs to deliver innovations. This capability would demonstrate a certain ‘technological breadth’ of knowledge that extends beyond firms’ own products, and would also demonstrate the ability to leverage supplier and other network-related partners to develop innovations and to ensure their fit with individual projects and broader industry needs. A networking capability like this would help technologically inclined PBFs find niches for new technologies and negotiate them into use (Manley, 2008; Pauget & Wald, 2013; Ritter & Gemünden, 2003; Salunke et al., 2011). Therefore, it is proposed that increasing levels of networking capability for PBFs will in turn increase the probability of introducing novel product innovations. The following hypothesis is progressed:

H2: Increasing levels of networking capabilities will relate positively to novel product innovations**.**

5.1.3. Adaptive and networking capabilities

Although both networking and adaptive capabilities are hypothesised to contribute to novel product innovation, it is expected that they do not operate in isolation from one another. It is argued that adaptive problem solving, at least with regard to novel product innovations, requires a commensurate level of networking capabilities. This is because innovation strongly supported by networks in PBFs. Any problem-solving effort that produces a new technology that will be used or integrated into larger systems must incorporate inputs from the focal firms’ network in order to be successful (Gann & Salter, 2000). Specifically, network interactions are key to successful development and diffusion of innovations in CoPS settings (Gann & Salter, 2000). For instance, suppliers are increasingly important to the development of innovations in the chemical industry because they have input into the subsystems that system integrators use to comprise final products (Brusoni et al., 2001). Customers and end users are also important. The adoption and diffusion of innovations, particularly in the case of new products, is very tightly bound to the users' needs, and requires significant interaction with them (von Hippel, 1994). If the diffusion affects many firms because it is somehow systemic (if multiple firms rely on it), then it also requires significant coordinated effort to diffuse the innovation through the network (Taylor et al., 2006; Taylor & Levitt, 2007). Such network dependencies mean that, even if a firm has high adaptive problem-solving capabilities, alone they will not necessarily translate directly into novel product innovation. The firm must also engage its network connections to ensure that the innovation fits with the needs of the industry, and to help improve the chances that the network will diffuse the innovation into the project (Manley, 2008), and to other businesses within the network (Taylor et al., 2006). Because networking capabilities are so important in facilitating innovation, it is anticipated that the adaptive problem-solving capabilities will actually operate through them. In other words, problem solving can lead to innovations, but their introduction hinges upon commensurate levels of networking capabilities. Networking capabilities ensure that the innovation establishes a niche in the project it targets, or that it is adopted by users (albeit limited in number) in support of the broader technological trajectory of the industry. Hence, the following hypothesis is progressed:

H3: Networking capability mediates the relationship between adaptive problem-solving capability and the introduction of novel product innovation.

The conceptual model for the capability constructs is shown in Figure 9. The top of the diagram shows the hypothesised relationship between networking and novel products (H1). The middle of the diagram shows the relationship between adaptive problem solving and novel products (H2). The bottom of the diagram shows the mediating effect of networking upon the relationship between adaptive capability and novel product innovation (H3).

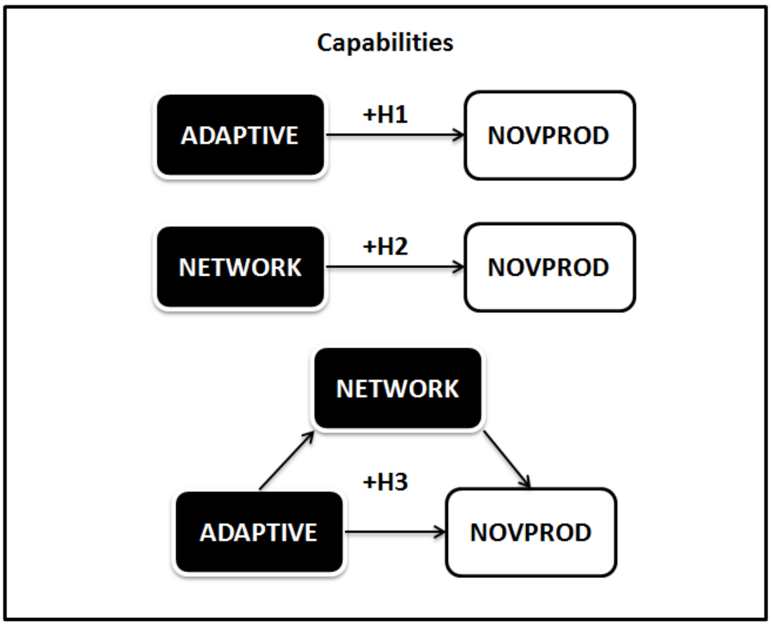

Figure 9 - Capability conceptual model

5.2. Model Testing

Five models are used to test the hypothesised relationships between capabilities and novel product innovation. Controls are tested in Model 1. Controls included in each model are R&D and the log transformed number of full time staff (LOGSIZE). The hypothesised relationships between adaptive problem solving, networking, and novel product innovation are tested separately in Models 2 and 3 (H1, H2). Model 4 tests both constructs in tandem (H1 and H2 simultaneously). In the tables and graphics, networking capability is denoted NETWORK. Adaptive problem solving is denoted ADAPTIVE. Model 5 reflects the variables needed for the test for mediation (H3). See Table 33.

Table 33 - Adaptive and Networking regression models

	Model	1	2	3	4	5‡
	Hypothesis	Controls	H1	H2	H1, H2	H3
IV	NETWORK			x	x	x
	ADAPTIVE		x		x	x
Controls	R&D	x	x	x	x	x
	LOGSIZE	x	x	x	x	x

‡Model is a moderation hypothesis and is depicted graphically in the text

5.2.1. Capability bivariate correlations

The Spearman's Rho bivariate correlation matrix and descriptive statistics for each variable are shown in Table 34. The descriptive statistics reveal that 20 per cent of the n=104 sample are novel product innovators. The mean of the networking capability is 3.0. The mean of the adaptive capability construct is 3.3. Both are measured out of five possible points on a

Likert scale average score.

The correlations matrix shows a positive relationship between novel product innovation and both capability constructs. Specifically, networking has a strong correlation (r_s =.311, p <.01, 2-tailed), and adaptive problem solving has a moderate correlation (r_s =.258, p <.01, 2-tailed) with novel product innovation. R&D moderate correlation with the novel project innovation as well (r_s =.216, p <.05, 2-tailed), and there is no such relationship for the firm size control. It is worth noting there that although networking and adaptive problem solving are relatively highly correlated (r_s =.638, p <.01, 2-tailed) the tests for multi-collinearity yielded no cause for concern.

Table 34 - Capability bivariate correlations

Spearman's Rho		n	M	S.D.	1	2	3	4
1	NOVPROD	104	0.20	0.40				
2	NETWORK	104	2.99	0.95	.311**			
3	ADAPTIVE	104	3.30	0.94	.258**	.638**		
4	R&D	104	0.55	0.50	.216*	.148	.120	
5	LOGSIZE	104	1.72	0.88	.067	.118	-.116	.075

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

5.2.2. Capability logistic regressions

A summary of the capability model results is shown in Table 35. The models reveal some support for H1, which is the direct relationship between adaptive problem solving and novel product innovation, and which is significant in the stand-alone Model 2, but loses significance in Model 4 when networking is also added to the regression. There is strong support for Hypothesis 2, where networking achieves significance both in the stand-alone Model 3, and the combined Model 4. Model 5, which tests a multi-step mediating hypothesis, is also supported as denoted in the table. Specific results are shown graphically in Figure 10. The controls only achieve traditional levels of significance where they are the only variables (Model 1). More detail is provided for each of models in the remainder of this section.

Table 35 - Summary of capability model results

Model	1		2		3		4		5
Hypotheses	*controls*		H1		H2		H1, H2		H3
	B	sig‡	B		B		B		
NETWORK					0.92	**	0.76	*	
ADAPT			0.78	*			0.28		Supported, see Figure 10
R&D	1.17	**	1.02	+	0.98	+	0.95		
LOGSIZE	0.12	**	0.25		0.05		0.11		
Constant	-2.32	***	-5.20	***	-5.05	***	-5.59	***	
Chi-square	5.28		11.64		14.86		15.26		
Sig.	0.07		0.01		0.00		0.00		
-2 Log likelihood	99.36		93.00		89.78		89.38		
Nagelkerke R Square	0.08		0.17		0.21		0.22		
Hosmer and Lemeshow Test	0.25		0.24		0.22		0.25		

‡One tailed test applied to main effects variables (Mina, Bascavusoglu-Moreau, & Hughes, 2014)

+ (*p* <0.1) * (*p* <.05) ** (*p* <.01) *** (*p* <.001)

Increasing levels of adaptive capabilities increase the odds of novel product innovation as shown in Table 36, which lends support to H1. The specific interpretation of the odds ratios in the model reveals that, as adaptive problem solving capabilities increases by one unit, the odds of novel product innovation increase by a factor of 2.19 ($p < .05$, one-tailed). Further, the confidence interval (CI) does not contain one (which would indicate neutral odds) suggesting that the direction of the effect is indeed positive. R&D appears to contribute as well (odds = 2.77, $p < .1$, two- tailed).

Table 36 - Capability Model 2, H1, Adaptive problem solving

NOVPROD					95% C.I.for Exp(B)	
Variables	B	S.E.	sig‡	Exp(B)	Lower	Upper
ADAPTIVE	0.78	0.34	*	2.19	1.12	4.28
R&D	1.02	0.57	+	2.77	0.90	8.54
LOGSIZE	0.25	0.31		1.28	0.70	2.35
Constant	-5.20	1.51	***	0.01		
Chi-square	11.64					
Sig.	.009					
-2 Log likelihood	93.00					
Nagelkerke R Square	.167					
Hosmer and Lemeshow Test	.236					

‡ One tailed test applied to main effects variables (Mina et al., 2014)

+ (*p* <0.1) * (*p* <.05) ** (*p* <.01) *** (p <.001)

Networking relates rather strongly to novel product innovation as shown in Table 37, which lends support to H2. The logistic model reveals that increasing networking by one unit increases the odds of novel product innovation by 2.51 (*p* <.01, one-tailed). And the CI ranges from 1.32 to 4.79, indicating a robust positive effect since it does not include 1 (which would infer a 50/50 probability). R&D is also significant with odds of 2.79 (*p* < .1, two-tailed).

Table 37 - Capability Model 3, H2, Networking

NOVPROD					95% C.I.for Exp(B)	
Variables	B	S.E.	sig ǂ	Exp(B)	Lower	Upper
NETWORK	0.92	0.33	**	2.51	1.32	4.79
R&D	0.98	0.59	+	2.67	0.85	8.41
LOGSIZE	0.05	0.31		1.05	0.57	1.94
Constant	-5.05	1.29	***	0.01		
Chi-square	14.86					
Sig.	.002					
-2 Log likelihood	89.78					
Nagelkerke R Square	.210					
Hosmer and Lemeshow Test	.220					

ǂ One tailed test applied to main effects variables (Mina et al., 2014)

+ (*p* <0.1) * (*p* <.05) ** (*p* <.01) *** (p <.001)

Table 38 shows details of Model 4 that contains both adaptive problem solving and networking capabilities. Networking retains significance (*p* < .05, one-tailed) and an odds ratio of 2.14. Adaptive problem solving does not achieve traditional levels of significance in this model as it appears to be overshadowed by networking capability.

Table 38 - Capability Model 4, H1 and H2, adaptive and networking

NOVPROD					95% C.I.for Exp(B)	
Variables	B	S.E.	sig [ǂ]	Exp(B)	Lower	Upper
NETWORK	0.76	0.41	*	2.14	0.95	4.81
ADAPTIVE	0.28	0.44		1.32	0.56	3.14
R&D	0.95	0.59		2.58	0.82	8.16
LOGSIZE	0.11	0.33		1.12	0.59	2.13
Constant	-5.59	1.59	***	0.00		
Chi-square	15.26					
Sig.	.004					
-2 Log likelihood	89.38					
Nagelkerke R Square	.215					
Hosmer and Lemeshow Test	.246					

[ǂ] One tailed test applied to main effects variables (Mina et al., 2014)

+ (p <0.1) * (p <.05) ** (p <.01) *** (p <.001)

To test H3—that networking mediates the effect of adaptive problem solving capabilities on novel product innovation—the *Process* tool plug-in for SPSS, which enables bootstrap confidence interval testing of the indirect effect, is used (Hayes, 2013). A strong indirect relationship was found, and adaptive problem solving appears to operate through networking to introduce novel products. The unstandardised indirect effect is .54 ($p < .05$, 1-tail) and the partially standardised indirect effect is 1.3, which is obtained by dividing the coefficient by the standard error of the outcome variable (Field, 2013). In the presence of networking, adaptive capabilities fails to gain significance (c’, Figure 10), suggesting that it is fully mediated by networking. This mediation finding is robust for three reasons: First, the CI for the indirect effect does not include zero, and this lends support to the fact that the direction of the effect is positive. Second, an additional moderation test was conducted using the *Process* tool; specifically, whether networking moderates the relationship between adaptive problem solving and novel product innovation. The interaction term was not significant for any portion of the range of values for the predictor variable. Third, an alternative mediation model where adaptive problem solving mediates the effect of networking on NOVPROD was tested and no indirect effect was detected. The results from the mediation analysis are shown in Figure 10.

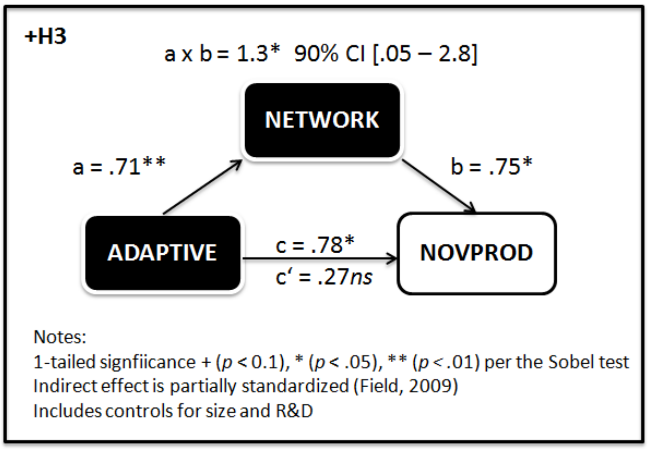

Figure 10 - Capability Model 5, H3, Networking mediates problem solving

A summary of the hypothesised relationships, findings, and the status is shown in Table 39. All three hypotheses are fully supported.

Table 39 - Capability innovation summary of hypotheses and results

Hypothesis		Findings	Status of hypothesis
H1	Increasing levels of adaptive capabilities will relate to novel product innovations.	Positive direct effect in the stand alone model. Odds 2.19 (p <.05).	Supported
H2	Increasing levels of networking capabilities will relate positively to novel product innovation.	Positive direct effect in both the stand alone model and that included adaptive problem solving capability. Odds 2.51 (p <.01).	Supported
H3	Networking capability mediates the effect of adaptive problem solving capability on the introduction of novel product innovation	Significant indirect effect found, indicating that adaptive problem solving operates through networking capabilities to novel product innovation. The unstandardised effect is .54. The standardised effect is 1.3 (p <.05). Path c' not significant suggesting 'full' mediation.	Supported

5.3. Discussion

Individually, adaptive problem solving and networking capabilities appear to be positively related to novel product innovation, providing direct support for H1 and H2. Each has a marked positive relationship with novel product introductions.

Adaptive problem-solving capability is comprised of innovative problem solving, ability to adapt to changing circumstances, and documenting and transferring lessons learned across projects, and is also a strong predictor of novel product innovation. The elements of problem solving and ability to change, which are encapsulated in this measure, are important to project-based firms because these firms operate in uncertain environments. Novel products, which originate from such an environment, require significant levels of problem solving (Ahola & Davies, 2012; Barlow, 2000; Stinchcombe & Heimer, 1985). The ability to take lessons learned from prior projects is another important element of the adaptive problem-solving construct. This addresses a major challenge to innovation in project-based environments, which involves the temporal separation of projects from each other and physical separation of project teams from their permanent organisations. This causes some knowledge about innovation—particularly 'know-how' an 'know-who'—to remain tacit rather than codified in organisational systems or processes (Gann & Salter, 2000). However, PBFs that are novel product innovators appear to remember past problem solving episodes to apply them to current problems. This, however, is not a routine that is maintained actively. Rather, it is a sporadic problem-solving activity, making it an ordinary rather than dynamic capability (Winter, 2003).

The networking capability, comprised of breadth of technological expertise, integration of supply chain partners, and other partner network arrangements, appears to significantly predict novel product innovations. Considering the interdependent nature of innovation in CoPS-like industry settings (Gann & Salter, 2000), it makes great sense that networking capability is an important determinant of novel product introductions. The findings suggest that project-based firms that increase their networking capability are potentially better able to leverage these enhanced network connections to develop and deliver new products into the market place. This includes strong connections to customers and suppliers in their supply chain, both to source the knowledge and technology going into the innovation, and to ensure that the products that are produced fit into the greater technological progression of the industry. Increased networking capability may also positively influence the diffusion of innovations, considering the high levels of interdependence that exist between firms. This interdependence means novel innovations have trouble diffusing, because multiple parties might need to adopt (nearly) simultaneously, as was the case for 3D design software in the US building construction industry (Taylor & Levitt, 2007). Thus, having a robust network of relationships (having higher networking capabilities), especially influential connections within the supply chain would likely translate into a higher likelihood of success in the introduction of novel product innovations.

However, as appealing as these individual explanations are, it is also apparent that these distinct capabilities do not operate in isolation. The mediating hypothesis (H3) predicted that adaptive problem-solving capability will operate through the networking capability. Indeed, support was found for this hypothesis, and, moreover, it appears that the mediation may be full rather than partial. That is to say that adaptive problem-solving capability is only as useful for novel product innovation as are firms' networking capabilities. Specifically, the moderating hypothesis means that when novel product innovators are faced with a critical challenge, they engage in problem solving. The problem-solving activity gives rise to inter-organisational networking. The latter may be the actual locus of innovation activity. The network may provide a catalyst for the problem-solving activity, it may be the arbiter of the usefulness of the innovation to the larger industry that might use it, and it may ultimately help to diffuse that innovation through the project-based productive network. This stepwise approach provides more fine-grained knowledge of the interdependent nature of innovation in project networks, and provides leads on the mechanisms that might spur firms to go outside their boundaries in the development of innovations (Gann & Salter, 2000).

5.4. Chapter summary

This chapter created and tested hypotheses regarding two capabilities thought necessary to explain how PBFs introduce capitalise on contingent opportunities in projects to produce novel product innovations. Adaptive problem solving and networking capabilities were found to be directly related to novel product innovation. However, a mediation relationship exists as well. Adaptive problem-solving capability is fully mediated by the networking capabilities of the firm.

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CHAPTER 6: STUDY TWO - OPEN INNOVATION

PBFs engage in significant levels of tacit knowledge sharing to develop innovations in CoPS settings (Gann & Salter, 2000). Knowledge sharing across firm boundaries is most specifically needed to coordinate design details between firms developing disparate aspects of CoPS (Acha, 2008), because of their nested and interdependent nature (Hobday et al., 2005). Specifically, PBFs are faced with the challenge of ensuring that their innovations fit within the broader technological context, by resolving system interface issues with complementary technology (Brusoni et al., 2001). This can be called a problem of technological interdependency. To address this problem, PBFs regularly engage in alliances (Jones & Lichtenstein, 2008) and co-engineering efforts (Gann & Salter, 2000), and they share intellectual property (Davies et al., 2011), among other pathways, to successfully deliver innovations in CoPS settings. These relationships that PBFs use are network-like, meaning they are not strictly buy-sell in nature (Gann & Salter, 2000). These network relationships thus engender fine-grained tacit knowledge exchanges that are important to supporting the development of novel innovations (Jones et al., 1997). For PBFs, these tacit knowledge flows occur in the context of large inter-organisational industry projects where many firms work together to negotiate the details of technological innovations (Miller & Lessard, 2000). But, we know little about the specific mechanisms that PBFs use to resolve the technological interdependence issue.

The open innovation literature has, for some time, concerned itself with inter-organisational knowledge flows to support innovation (Chesbrough & Bogers, 2014; Chesbrough, 2003), and thus it offers a lens to view the phenomena of PBFs resolving technological interdependencies in the novel product innovation development process. Non-pecuniary flows—those that do not involve financial transactions—are closely aligned the concept of tacit knowledge flows in networked environments in that they are not strictly buy-sell exchanges of information, but are more intimate and less costly affairs (Dahlander & Gann, 2010). The inbound, non-pecuniary form of open innovation called *sourcing* is the ingesting of knowledge that comes from existing partner connections, or other sources, that the firm already has access to which do not incur additional direct costs (Dahlander & Gann, 2010). Operationalised as search breadth (Laursen & Salter, 2006), sourcing is argued to support novel product innovation as a response to problems arising from uncertainty (Leiponen & Helfat, 2010), or to overcome learning challenges of project-based organising that may lead to knowledge remaining tacit and perhaps hard to locate in times of need (Gann & Salter, 2000). The out-bound, non-pecuniary form is *revealing* intellectual property and real technical detail about innovations to others with no immediate financial benefit (Dahlander & Gann, 2010). Revealing is used as a strategy in industries where intellectual property rights are well protected. Revealing drives new product development efforts by facilitating co-development with customers, by spurring the interest of potential customers, and by ensuring system interfaces align (Henkel & Baldwin, 2010; Henkel & Maurer, 2009; Henkel et al., 2013). Revealing thus seems a useful strategy for PBFs to overcome the technological interdependencies issue.

The remainder of the chapter is organised into four parts. The first section develops hypotheses for non-pecuniary types of open innovation—*sourcing* and *revealing*. In this section, effort is also undertaken to establish the mediating role of R&D in these relationships, since it is highly relevant to firms' ability to leverage external knowledge flows for the purposes of developing and commercializing innovations (Cohen & Levinthal, 1990). The second section shows the results of model testing effort, and indicates acceptance or rejection of the hypotheses. A third section discusses the results in more detail. A fourth section summarises the chapter. Detailed summary and conclusion are reserved for Chapter 5.

6.1. Hypotheses

This section discusses the theoretical justification for hypotheses for non-pecuniary, in-bound, sourcing and non-pecuniary, outbound, revealing.

6.1.1. Non-pecuniary, in-bound sourcing

The development of technologies in by PBFs in CoPS settings is characterised by complex interactions between technologies that are negotiated into use by project participants (Miller & Lessard, 2000) and firms supporting the technological trajectory of the industry (Whitley, 2002, 2006). In this context, interdependencies between component and sub-systems give rise to emergent technical issues that are resolved through nested cycles of design iterations (Nightingale, 2000). Often these issues or problems arise without warning, and require innovative problem-solving approaches to resolve them (Stinchcomb and Heimer, 1985). Launching a search for an answer is known as *problemistic search*, and broad search patterns will increase the potential that a novel combination of information can be found that satisfactorily addresses the problem (Cyert & March, 1963; Greve, 2003; Leiponen & Helfat, 2010). Another reason that PBFs will likely search broadly is because they operate inside temporary projects. This means project teams are often physically and operationally separated from permanent organisational structures of the core business. PBFs are therefore challenged in their ability to learn by storing past experiences in permanent organisational repositories;

thus, their ability to draw upon past experiences may be limited, and some of this gained knowledge remains tacit rather than codified (Gann & Salter, 2000; Prencipe & Tell, 2001). This means that finding novel information may be difficult, and broad search may be a strategy to combat the learning problems and the resulting lack of innovation information available in the operating environment (Garriga et al., 2013).

However, there are also potential downsides to searching broadly. Where technological dynamism is low—as is the case in CoPS settings like oil and gas (Acha & Cusmano, 2005; Whitley, 2006)—broad search may decrease the probability of novel innovation (Sidhu et al., 2007). This is because when established technological systems are relatively stable, industry innovation activity will be closely tied to maintaining and improving current products associated with the industry dominant designs. This removes the motive to search further afield, and hence the need to search broadly (Henderson & Clark, 1990; Sidhu et al., 2007). Further, PBFs may be limited in terms of resources (staff and costs) to engage in broad search anyway (Keegan & Turner, 2002; Lampert & Semadeni, 2010). However, narrow search does not necessarily mean that novel innovation cannot be achieved. Although search activities may fall closely to existing knowledge sets (Helfat, 1994; Levinthal & March, 1993), novel product innovation can be derived from combinations of existing knowledge and limited information obtained elsewhere (Cohen & Levinthal, 1990; Gatignon et al., 2002). The development of completely new solutions is not only in the domain of completely new knowledge, but is also dependent upon the ability to arrive at new combinations of existing knowledge (Katilia & Ahuja, 2002; Schumpeter, 1934).

For PBFs, it is broad search is expected to relate to novel product innovations most clearly. This is because of the prevalence of inherent uncertainties associated with developing technologies in large projects (Stinchcombe & Heimer, 1985) and the likelihood that they will spur problemistic search the problems arising that need resolution are likely drive broad search strategies to increase the probability a solution is found (Leiponen & Helfat, 2010). Further, broad search seems a suitable response to solving problems that arise in a discontinuous learning environment where knowledge is not codified and remains tacit (Gann & Salter, 2000). Between the frequent problems arising in projects and the learning challenges that PBFs face, it is likely broad information search will inform innovation activities. Therefore, as PBFs increase the breadth of their search patterns, the probability of novel innovations will increase. Thus, the following hypothesis is progressed:

H1: Sourcing will positively relate to novel product innovation.

To better understand the relationship between sourcing and novel product innovations, it is necessary to investigate how firms' R&D activities affect this relationship. Cohen and Levinthal (1990) argue that R&D not only performs an internal inventive function, but also has another face. R&D is also a component of firms' 'absorptive capacity', which is the ability to recognise, assimilate, and transform external knowledge into viable commercial outcomes (Cohen & Levinthal, 1990). Their original conception of this absorptive capacity revolved around the ability of the firms' existing R&D enterprise as a tool to usefully cull the value of external information. That is to say, R&D activities provide the necessary antennae to perceive the value of information, to collect it and transform it into useful forms that can be integrated into firms' innovation processes, and to provide insights into commercialisation pathways. And indeed, there is much literature supporting the theory that absorptive capacity enables firms to deliver commercially viable product innovations (Cohen & Levinthal, 1990; Lane et al., 2006; Loene & Reichstein, 2012). Thus, the ability to utilise sourced information in the development of novel products will depend upon the conduct of R&D activities in PBFs, since this represents a dedicated investment in knowledge-translating capability (Moilanen et al., 2014). Therefore:

H1a: R&D will positively mediate the relationship between sourcing and novel product innovations.

6.1.2. Non-pecuniary, outbound revealing

Revealing is the non-pecuniary outbound disclosure of knowledge to the public or external environment without any immediate prospect of compensation or reward (Dahlander and Gann, 2010). Revealing is foremost a development strategy (Henkel & Maurer, 2009; Henkel et al., 2013). Firms selectively reveal information about innovations in order to co-create new products with customers (Henkel et al., 2013). Bringing firms into the development process leads to more rapid specialisation of products for customers (Henkel et al., 2013). The importance of revealing as a co-development activity for innovation is argued to exist in environments where intellectual property is protected strongly, and with limited customer sets (Henkel & Maurer, 2009). Although this concept was originally developed in the software industry, strong intellectual property rights also exist in CoPS industries (Whitley, 2006) and, in particular, the oil and gas industry (Acha & Cusmano, 2005; Perrons & Donnelly, 2012).

There is support for the notion that CoPS-related novel products require revealing activities, mostly due to the iterative negotiation among participants that is part and parcel to the design process in CoPS projects (Miller & Lessard, 2000; Nightingale, 2000). The development process is decidedly a non-linear process, requiring iterative design cycles to establish system and subsystem efficacy, and resolving system interface and interdependency problems along the way (Nightingale, 2000). Thus, PBFs may reveal details about their innovations in order to ensure the interfaces with other systems and subsystems are copacetic (Gann & Salter, 2000; Hobday et al., 2005). Beyond the need for revealing in the development process, it also aids the diffusion of innovations by drawing interest from customers (Harhoff et al., 2003) convincing network partners they should adopt new products (Taylor et al., 2006). In the context of single projects, revealing is an important element of enticing customers them to integrate new products into larger systems being delivered in the project (Gil et al., 2012; Henkel & Baldwin, 2010). In this way, revealing represents the exchange of detailed innovation to support novel product development and to support the acceptance of said innovation by customers. Increased levels of revealing will, therefore, be related to a higher probability of introducing a novel product innovation. Therefore, it is hypothesised that:

H2: Revealing will positively relate to novel product innovation.

Because revealing is suspected to be, at least in part, a co-development activity, it is argued to operate in conjunction with firms’ R&D activities. Revealing is conceptualised to precede commercialisation efforts, as firms negotiate the features of product innovations and resolve system interface issues in the design processes. The mechanism proposed here involves three steps. First revealing information helps to ensure that the novel product development effort is on track to meet customers’ expectations in terms of features and functionality, and to resolve system interface issues with complementary technologies. Second, this action solicits feedback and, perhaps, direct involvement by the customer to co-create the technology. Third this feedback, directly from primary customers and other potential adopters in the network, is used as an input into subsequent R&D to refine the novel product. It is these further R&D activities that will bring the nascent technology to commercial fruition, and the prior revealing steps have helped to smooth the way. Put simply, revealing solicits feedback that becomes an input into R&D, and subsequent R&D leads to the commercialisation of the product. This stepwise process is hypothesised to support the introduction of novel product innovations for PBFs. Therefore, the following hypothesis is progressed:

H2a: R&D will positively mediate the relationship between revealing and novel process innovation.

Figure 11 depicts the conceptual model for open innovation and all of the hypothesised relationships.

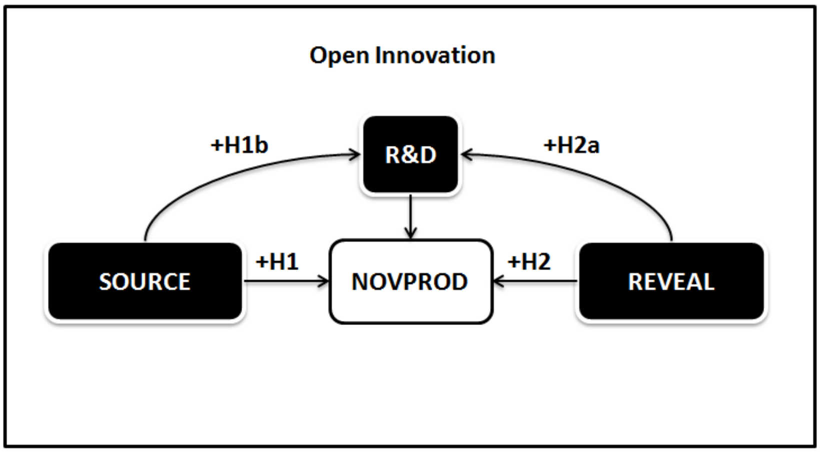

Figure 11 - Open innovation conceptual model

6.2. Model testing

Six models are necessary to test the hypotheses for open innovation. Model 1 tests the controls alone. Model 2 tests the direct relationship between sourcing and novel product innovation. Model 3 tests the direct relationship between revealing and novel product innovation. Model 4 tests the direct relationships of sourcing and revealing to novel product innovation, in tandem. Models 5 and 6 test the mediating effect of R&D on the relationship between sourcing and novel products, and revealing and novel products, respectively. These mediation models also include control variables. In the table and the subsequent diagrams, novel product innovation is referred to as NOVPROD. Independent variables of *sourcing* and *revealing* are denoted SOURCE and REVEAL, respectively. Controls include R&D, firm size (LOGSIZE) and the POC is tri-level control variable capturing year surveyed year 1 (encoded 1), year 2 (encoded 2), and whether firm is a panel firm (encoded 3). See Chapter 4 for details of the variables. The model structures are shown in Table 40.

Table 40 - Open innovation regression models

	Model	1	2	3	4	5‡	6‡
	Hypothesis	Controls	H1	H2	H1, H2	H1a	H2a
IVs	SOURCE		x		x	x	
	REVEAL			x	x		x
Controls	R&D	x	x	x	x	x	x
	POC	x	x	x	x	x	x
	LOGSIZE	x	x	x	x	x	x

‡Models results are shown diagrammatically

6.2.1. Open innovation bivariate correlations

Table 41 shows the descriptive statistics and Spearman's bivariate correlations for the variables. Sourcing does not have a significant relationship to novel product innovation. Revealing appears to be significantly and positively related to novel product innovation. The control for panel firms (POC) indicates that they are not likely to be novel product innovators.

Table 41 - Open innovation bivariate correlations

Spearman's Rho		n	mean	SD	1	2	3	4	5
1	NOVPROD	121	0.42	0.50					
2	SOURCE	121	6.79	3.13	-.136				
3	REVEAL	121	0.96	0.78	.220*	.236**			
4	RD	121	0.60	0.49	.261**	.057	.282**		
5	POC	121	1.73	0.74	-.220*	-.049	-.058	.073	
6	LOGSIZE	121	1.90	0.88	-.020	.040	.138	.199*	.074

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

6.2.2. Open innovation logistic regressions

A summary table of results for is shown in Table 42. The summary table reveals no support for H1, which hypothesised a positive relationship between sourcing and novel product innovation. In fact, the sign for sourcing is negative and significant, indicating the opposite relationship exists than was hypothesised, as seen in Models 2 and 4. There is significant support for H2, which is a positive relationship between revealing and novel product innovation, as shown in Models 3 and 4. The moderating hypotheses tested in Models 5 and 6 follow the multi-step approach of Baron and Kenny (1986) and are presented graphically in subsequent discussion in this section. For summary purposes, support is not found for H1a—that R&D mediates the relationship between sourcing and novel product innovation. Support is, however, found for H2a—that R&D mediates the relationship between revealing and novel product. Each of the hypothesised models is discussed in turn, next.

Table 42 - Summary of open innovation regression model results

Model	1		2		3		4		5	6
Hypotheses	*controls*		H1		H2		H1, H2		H1a	H2a
	B	ǂsig								
SOURCE			-0.12	*			-0.17	**	*Not supported see* Figure 12	*Is supported see* Figure 13
REVEAL					0.42	+	0.64	*		
R&D	1.34	**	1.42	**	1.17	**	1.22	**		
POC	-0.70	*	-0.75	**	-0.66	*	-0.73	*		
LOGSIZE	-0.16		-0.15		-0.20		-0.20			
Constant	0.34		1.16		0.04		1.06			
Chi-square	15.85		19.32		18.27		24.21			
Sig.	0.00		0.00		0.00		0.00			
-2 LL	148.9		145.4		146.7		140.5			
R Sq	0.17		0.20		0.19		0.24			
H&L	0.55		0.76		0.34		0.91			

ǂOne tailed test applied to main effects variables (Mina et al., 2014)
+ (p <0.1) * (p<.05) ** (p<.01) *** (p<.001)
H&L = Hosmer and Lemeshow; R Sq = Nagelkerke; -2LL = – 2 Log Likelihood

Table 43 shows the detailed results for Model 2. Sourcing is shown to have a negative relationship to novel product innovation, with an odds ratio of .89 ($p < .05$, one-tailed). Strictly speaking, increasing sourcing by one unit (increasing search breadth by one unit) decreases the odds of a novel product innovation by .89. Per Equation 1, this translates to just around a 47 per cent chance that increasing search breadth by one unit will help novel product innovation. The 95 per cent CI ranges from .78 to approximately 1, which means there is a strong likelihood indeed that this is a negative relationship.

Table 43 - Open innovation Model 2, H1, Sourcing

NOVPROD					95% C.I.for Exp(B)	
Variables	B	S.E.	ǂsig	Exp(B)	Lower	Upper
SOURCE	-0.12	0.07	*	0.89	0.78	1.01
R&D	1.42	0.44	**	4.14	1.75	9.78
POC	-0.75	0.28	**	0.47	0.27	0.83
LOGSIZE	-0.15	0.23		0.86	0.55	1.35
Constant	1.16	0.79		3.20		
Chi-square	19.32					
Sig.	.001					
-2 Log likelihood	145.43					
Nagelkerke R Square	.198					
Hosmer and Lemeshow	.757					

ǂ One tailed test applied to main effects variables (Mina et al., 2014)

+ (p <0.1) * (p<.05) ** (p<.01) *** (p<.001)

Table 44 shows the detailed results for Model 3. Revealing is shown to have a significant and positive relationship to novel product innovation, with an odds ratio of 1.52 ($p < .1$, one-tailed) and providing support for H2. As revealing increases, the odds of novel product innovation increase by a factor of 1.52, with a CI ranging from .9 to 2.6. The CI includes 1, so the support for the hypothesis is limited.

Table 44 - Open innovation Model 3, H2, Revealing

NOVPROD					95% C.I.for Exp(B)	
Variables	B	S.E.	ǂsig	Exp(B)	Lower	Upper
REVEAL	0.42	0.27	+	1.52	0.89	2.58
RD	1.17	0.44	**	3.22	1.35	7.66
POC	-0.66	0.28	*	0.52	0.30	0.90
LOGSIZE	-0.20	0.23		0.82	0.52	1.29
Constant	0.04	0.67		1.04		
Chi-square	18.27					
Sig.	.001					
-2 Log likelihood	146.47					
Nagelkerke R Square	.188					
Hosmer and Lemeshow	.341					

ǂ One tailed test applied to main effects (Mina et al., 2014)

+ (p <0.1) * (p<.05) ** (p<.01) *** (p<.001)

Model 4, which contains both forms of non-pecuniary open innovation, is shown in Table 45. Sourcing is shown to have a negative relationship with novel product innovation. As sourcing increases by one, the odds of novel product innovation change .84 (a decrease)

(p < .01, one-tailed). This finding is an even stronger falsification of the H1, achieving high levels of significance. Because search breadth was used as a proxy for sourcing, this finding means that as search breadth *increases,* novel product innovation probability *decreases*. The reverse is also true. That is, as search breadth *decreases,* the odds of novel product innovation *increase.* Odds of .84 translate to 45.6 per cent chance that increasing search breadth by one unit will lead to a novel product innovation by using Equation 1. This means that decreasing search breadth by one unit confers a 54.4 per cent chance that novel product innovation will occur. Thus it appears that narrow, not broad, search relates to novel product innovation. H1 is therefore formally rejected since the opposite of the hypothesised relationship was found.

The relationship between revealing and novel product innovation is positive and significant, with odds of 1.79 (p < .05). This provides stronger support for H2 than does Model 3, where revealing was tested alone. Odds improve anywhere from 1.06 up to 3.41 that a novel product innovation will occur when revealing is increased by one unit, according to the 95 per cent CI. Thus, H2 is formally accepted based on this strong support. In terms of controls, R&D shows an expected positive relationship to novel product innovation. The POC variable indicates that the panel firms in the sample are not likely novel product innovators. No relationship was found with firm size.

Table 45 - Open innovation, Model 4, H1 and H2, Sourcing and revealing

NOVPROD					95% C.I.for Exp(B)	
Variables	B	S.E.	ǂsig	Exp(B)	Lower	Upper
SOURCE	-0.17	0.07	**	0.84	0.73	0.97
REVEAL	0.64	0.30	*	1.90	1.06	3.41
R&D	1.22	0.45	**	3.39	1.40	8.21
POC	-0.73	0.29	*	0.48	0.27	0.85
LOGSIZE	-0.20	0.24		0.82	0.52	1.30
Constant	1.06	0.81		2.87		
Chi-square	24.21					
Sig.	.000					
-2 Log likelihood	140.5					
Nagelkerke R Square	.244					
Hosmer and Lemeshow	.908					

ǂ One tailed test applied to main effects variables (Mina et al., 2014)

+ (p <0.1) * (p<.05) ** (p<.01) *** (p<.001)

When testing H1a—that R&D mediates the relationship between sourcing and novel product innovation—no support is found. Via the Baron and Kenny framework, it was found that *path a* is not significant, meaning that sourcing does not predict R&D. Therefore, the joint test of significance of the mediating effect automatically fails (*path a* and *path b* are both required to be significant). Additional robustness tests were conducted on this finding. A moderation test of R&D's impact on the relationship between sourcing and novel product innovation found no support. A reversed mediation hypothesis was also tested, and this also yielded no significant result. Therefore, H1a is formally rejected. See Figure 12.

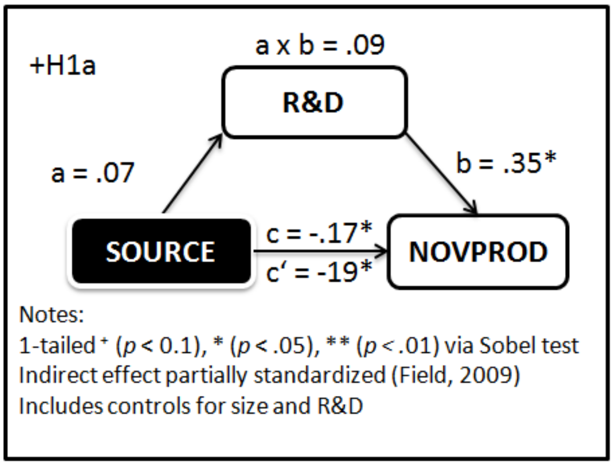

Figure 12 - Open innovation, Model 5, H1a, R&D does not mediate sourcing

Support was found for H2a, that R&D mediates the relationship between revealing and novel products. Based on the Baron and Kenny (1986) approach, a partially standardised indirect effect of .19 (p <.05) was found based on the joint test of significance. This indicates that revealing operates through firms' R&D. This supports the contention that revealing is a developmental activity, rather than only a diffusion activity (Henkel et al., 2013). Revealing solicits feedback from customers, which is absorbed into the development effort, which in turn supports novel product innovations. This mechanism provides insight into how revealing solicits inputs to the product development machinations of project-oriented firm. In the tests for robustness, no evidence was found of a moderation effect of R&D on the relationship between revealing and novel product innovations. In addition, testing for the alternative mediation (that revealing mediates the effect of R&D on novel product innovations) did not yield a statically significant indirect effect. See Figure 13.

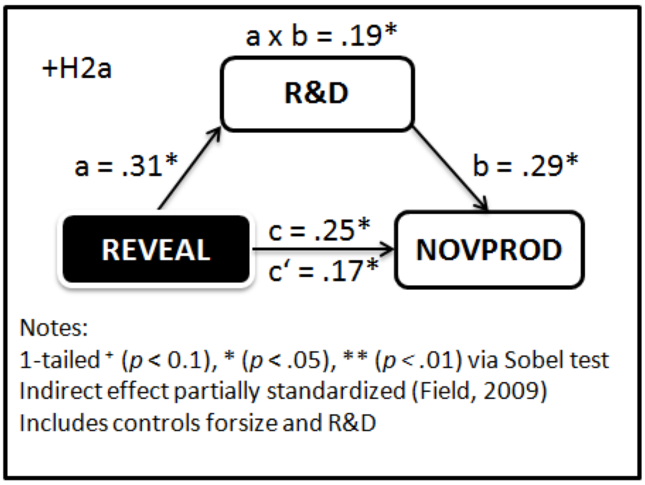

Figure 13 - Open innovation, Model 5, H2a, R&D mediates revealing

Table 46 summarises the four hypothesised relationships and succinct details of the findings. Overall, two hypotheses are supported; two are rejected.

Table 46 - Open innovation summary of hypotheses and results

Hypothesis		Findings	Status of Hypothesis
H1	Sourcing will positively relate to novel product innovation.	Sourcing is negatively related to novel product innovation. Odds .84 (p < .01).	Rejected
H1a	R&D will positively mediate the relationship between sourcing and novel product innovations.	Sourcing does not predict R&D (the mediator).	Rejected
H2	Revealing will positively relate to novel product innovation.	Direct positive relationship. Odds 1.9 (p < .05).	Supported
H2a	The relationship between revealing and novel process innovations is mediated by R&D.	Partially standardised indirect effect of .19 (p <.05) was found.	Supported

6.3. Discussion

6.3.1. Sourcing

In terms of sourcing, no support was found for the hypothesised positive relationship. Instead, a negative relationship between sourcing (operationalised as search breadth) and novel product innovation was found. The findings show that narrow search, rather than broad search, is positively related to novel product innovation. Further, no support was found for the hypothesis that absorptive capacity mediates the effect of sourcing on novel product innovations. These adverse findings on sourcing require explanation because the basis of the construct is broad search, which has been consistently tied to novel product innovations in many settings (Katilia & Ahuja, 2002; Laursen & Salter, 2006).

A first potential explanation is that in low-velocity settings where dominant designs are prevalent, firms deliver innovations that complement existing technological systems (Henderson & Clark, 1990; Sidhu et al., 2007). The firm will search locally for information to support this closely related innovation, and thus exhibit constrained or narrow search patterns (Helfat, 1994; Levinthal & March, 1993). Firms do not examine each and every potential alternative, because bounded rationality constrains the recognition of distant alternatives (Helfat, 1994). Most learning related to innovation is associative in nature, and learning occurs in close proximity to existing knowledge sets (Helfat, 1994; Levinthal & March, 1993; Wang et al., 2014). Novelty hinges on firms' abilities to leverage existing capabilities associated with existing products, with whatever new information obtained from outside the firm (Cohen & Levinthal, 1990; Gatignon et al., 2002). Thus, novelty does not mean that all the of the information associated with the innovation is new, but that rather a novel combination of existing and new knowledge has been accomplished (Arthur, 2009; Katilia & Ahuja, 2002; Schumpeter, 1934).

A second potential explanation is based on the prevalence of revealing. When novel innovators reveal information about their technologies, this can give rise to an operational environment that is rich with detailed information. This practice, in aggregate, may lead firms into narrower search strategies because the prevalence of rich information decreases the need to search broadly for high-quality information (Garriga et al., 2013).

A third explanation relates to the simple operationalisation of the presence of R&D that may affect both the direct relationship to novel products and the proposed mediating relationships that put R&D between the sourcing activity and the introduction of novel products. The operationalisation of R&D used herein is a binary variable indicating the presence of R&D (Moilanen et al., 2014). As a control, R&D positively relates to novel innovation. As a direct effect, this operationalisation does not allow differentiation between the various levels of absorptive capacity that firms would exhibit. R&D intensity would, for instance, provide some differentiation among firms. Such an operationalisation was not possible due to limitations in the data set. Could R&D intensity be operationalised, alternative explanations could be tested. These include improved understanding of direct relationships, and whether or not high levels of absorptive capacity might lead to more targeted (narrow) and less costly search patterns (Cohen and Levinthal, 1990). It also could improve the understanding of the mediating relationship, and help to understand whether high R&D intensity is necessary to convert broad search patterns into novel innovations.

A fourth alternative may be that search is an inappropriate operationalisation for inbound non-pecuniary flows. Based on the fact that narrow search appears to relate to novel product innovation, additional models were run that operationalised sourcing as depth instead of breadth (Laursen & Salter, 2006). Depth represents more specific innovation channels suspected to be drawn upon heavily particularly in the development of novel innovation in particular (Laursen & Salter, 2006). Depth was operationalised as the number of sources cited as “very significant” or “crucial” (a 4 or 5on a 5-point Likert scale, M=1.3, SD=1.9, α=.73, 12 items). However, this analysis found no direct relationship between depth and novel product innovation in an analog of Model 4, where sourcing was operationalised as depth instead of breadth.

A fifth alternative explanation is that broad search relates to incremental innovations (those only new to the firm, and not to the industry). This is because firm search strategies may remain constrained by the existing knowledge bases, creating a myopia that keeps search local and in turn leads to incremental innovations rather than novel (Levinthal & March, 1993). Indeed, the original conception of a search (specifically problemistic search) links it closely to ongoing and problem-solving activities (March, 1963). Project-based firms may similarly be subject to myopia, constrained by ongoing close collaborations that are repeated across time. Close coordination with similar actors in the conduct of projects is similar to the way that firms might interact with the same customers again and again. This repetition serves to reinforce existing product offerings and incremental innovations associated with them (Atuahene-Gima, 2005; Knudsen, 2007). To test the relationship between broad search and incremental products, the difference in mean search levels between two groups (incremental product innovators, and not) was tested using the non-parametric Mann-Whitney test[8]. This simple test provides some evidence that incremental product innovators do exhibit slightly higher levels of search. The estimated effect size is .17, and is positive and significant (median = 7, U =1310.5, Z = -1.81, $p < .05$ (exact, 1-tailed), r = .17).

6.3.2. Revealing

A direct positive relationship between revealing and novel product innovation was found. The finding highlights the importance of non-pecuniary outbound knowledge flows, which are already expected to occur in high-technology settings like biotech and computing, where IP rights are strongly enforced. However, the literature supports the assertion that

[8] This test was conducted because there were too few instances of incremental product innovations in the sample to run a stable logistic model that also included all the same independent and control variables used in the novel product innovation models.

PBFs, particularly those operating in independent innovation environments exemplified by CoPS projects (also with strong IP regimes), would also engage in this practice. PBFs would reveal to specifically primarily as co-development strategy necessary to resolve the problem of technology interdependencies, and secondarily to gain support for innovations from customers. The finding that revealing operates through the R&D activities of firms suggests that firms reveal as part of their novel product development processes, rather than solely to aid in adoption and diffusion of innovation.

The direct relationship between revealing and novel products, and the fact that this relationship is mediated by R&D as part of a co-development process, provides empirical evidence to support theoretical arguments that PBFs must regularly reach across their boundaries to ensure that their products fit the needs of current clients and fit into the broader technological trajectory of the industry (Gann & Salter, 2000). As Gann and Salter (2000) argue, firms operating in project-based productive networks intensely collaborate across their boundaries as a rule, and this collaboration does not always occur purely in buy-sell relationships. Innovation relies upon intimate network-like relationships that occur in the context of projects (Gann & Salter, 2000; Manley, 2008). Close inter-organisational relationships within projects to develop innovations have been noted in the oil and gas industry especially (Barlow, 2000; Bower et al., 1997; Daneshy & Donnelly, 2004). As Bower et al., (1997, p. 346) put it, 'While leading-edge firms may come up with innovative product ideas, and undertake some independent development, much of the development process is dependent on physical access to, for example, the client's oil well'. This collaborative, interdependent, and intimate spirit is embodied in the construct for revealing, specifically because the construct contains two types of revealing—representing outbound information flows that are specifically focused on motivating problem solving activities or to develop innovations further. To reiterate, the components of this construct are *open sharing*—sharing 'technical details openly to the industry to spur subsequent innovation or adoption of technology (e.g., any way that real technical detail is shared externally but with no immediate direct monetary benefit)'—and *closed sharing*, which is the revealing of 'technical information via confidentiality agreements in order to explore potential larger partnerships or licensing opportunities'.

6.4. Chapter summary

This chapter informs the open innovation debate and at the same time raises additional questions. Foremost, the study reveals that non-pecuniary knowledge flows do play important roles in the development of novel product innovation for PBFs. The argument is that non-pecuniary flows reflect the tacit and intimate knowledge flows that accompany the development of interdependent components, subsystems, and CoPS that support the industry. These types of knowledge flows reflect the networked nature of innovation that PBFs strive to participate in. One particular finding is that non-pecuniary outbound revealing not only has a direct relationship to novel product innovation, but is also a developmental process, since it operates through firms' R&D. Revealing also solicits input from customers, which is useful for the subsequent novel product development and commercialisation process. This was thought to be prevalent in high-technology realms, but it is found here to exist in an engineering-intensive environment. Thus, the phenomena may be much more prevalent than originally thought (Henkel et al., 2013). The study has some interesting findings relative to non-pecuniary inbound knowledge flows. Sourcing, operationalised as broad search (perhaps the most popular construct in the open innovation sphere), was found to be negatively related to novel product innovations. The alternative is also true, that narrow search positively relates to novel product innovation. Some potential explanations for this finding were explored in the discussion section.

CHAPTER 7: STUDY THREE - STRUCTURAL EMBEDDEDNESS

PBFs in CoPS settings repeatedly interact with one another across projects, and this structure of patterned relationships comprises a network that facilitates both the conduct of projects, and the delivery of innovation in CoPS industries (Gann & Salter, 2000). Firms with structured, patterned relationships are often referred to as being embedded in networks. Both the social capital literature (Granovetter, 1985; Jones et al., 1997; Uzzi, 1997) and the project literature (Bakker et al., 2011; Bakker, 2010; Jones & Lichtenstein, 2008) point to embeddedness as a primary means to explain the more intimate nature of transactions between firms in settings where close collaboration with other firms is prominent, and buy-sell exchanges are not always clear-cut. Embeddedness specifically helps to improve coordination between firms by promoting a shared understanding of roles, reducing maleficent behaviour by engendering trust between partners, and by supporting problem-solving activities (Bechky, 2006; Jones & Lichtenstein, 2008). Embeddedness between firms is specifically thought to support the fine-grained sharing of tacit knowledge important to innovation (Jones et al., 1997; Uzzi, 1997). However, over-embeddedness may limit firms' ability to introduce novel product innovation. Closed network structures limit new (potentially valuable) information from outside firms' immediate network partners (Burt, 2004; Uzzi, 1997). Specific to PBFs, over-embeddedness with suppliers and customers may prevent the firm from breaking away from the incremental technological change regime that typifies most CoPS industries (Whitley, 2002).

To shed light on this subject, this chapter focuses on structural embeddedness, which is the social network terminology adopted to reflect the inter-organisational relationships that exist between firms that operate in networks (Jones et al., 1997; Jones & Lichtenstein, 2008). Structural embeddedness is defined herein as the firm-level decision to engage in inter-organisational relationships, and it is operationalised via proxy based on the patterns of formal collaborations that the firm maintains, based on the idea of geographic embeddedness (Collinson & Wang, 2012; Love et al., 2010; Song et al., 2011). Here, particular attention is paid to supplier and customer embeddedness (Whitley, 2002). This attention is warranted by the very interdependent nature of technology development that is contextualised by large industry projects involving many cooperating firms (Gann & Salter, 2000).

The rest of this chapter is organised as follows. The first subsection presents the hypotheses. These are arranged in terms of supplier embeddedness, customer embeddedness, supplier over-embeddedness, customer over-embeddedness, and vertical embeddedness, the latter which refers to being dually embedded with customers and suppliers at the same time.

Contributing to the formulation of these hypotheses are literatures of innovation, projects, temporary organising, and social capital. Second, the models are tested and the results presented. The third section discusses the implications of the findings. A fourth section presents a succinct summary of the chapter. Detailed summary and conclusions are reserved for the final chapter, Chapter 5.

7.1. Hypotheses

7.1.1. Supplier embeddedness

Suppliers embody diverse knowledge required to produce components and subsystems, which are important elements of CoPS-related novel product innovations (Brusoni et al., 2001). Supplier structural embeddedness is the basis of a combinatory approach to innovation, which is based on firms recombining the capabilities of their suppliers into different bundles to support the idiosyncratic nature of new technology development efforts in CoPS settings (Davies & Hobday, 2005). The innovation literature bears this out by showing that, as development partners, suppliers are often sources of cutting-edge technologies and processes that contribute positively to new product innovation outcomes (Knudsen, 2007; Tidd & Bodley, 2002; Wagner & Hoegl, 2006). PBFs often build innovations by directly involving suppliers in the design and engineering activities (Brusoni, 2005; Martinsuo & Ahola, 2010). Moreover, suppliers are increasingly integrated into customer operations by supplying integration, operation, and maintenance services. The direct involvement of suppliers in the innovation development and transition processes greatly increases the potential for innovation improvements due to the close proximity and close working relationships these acts engender (Davies et al., 2007). Thus, there is reason to believe that supplier embeddedness will positively influence novel product innovation for PBFs.

The case against the negative role of supplier embeddedness is slim, and focused on market elements that are not directly applicable to PBFs in CoPS settings. For instance, supplier involvement in commercialisation stages of technology have been shown to be of little importance to commercial success (Tidd & Bodley, 2002). Also, market intelligence provided by suppliers may hurt innovation performance (Song & Thieme, 2009). However, these insights are based on observations of innovation diffusion problems for manufactured goods, and regard the problems associated with market uncertainty and shifting customer needs and preference associated with those realms (Bohlmann, Spanjol, Qualls, & Rosa, 2013). Thus, these insights are perhaps not directly applicable to limited and well-defined markets that characterise CoPS-related novel products (Hobday, 1988).

Thus, the theoretical argument remains strong for supplier embeddedness in CoPS settings. The increasing levels of supplier embeddedness provide opportunities to develop and improve innovations for PBFs. Thus increasing supplier embeddedness will increase the chances of novel product innovation, and the hypothesis is progressed that:

H1: Supplier embeddedness will relate positively to novel product innovation.

7.1.2. Customer embeddedness

Customers are important influencing parties in the development of novel product innovations. Customers provide impetus for innovation by bringing to light particular technological challenges, and often originate ideas regarding prototypes (Franke, 2013; von Hippel, 2007). Customers provide the impetus and vision for novel instantiations in CoPS settings (Davies & Hobday, 2005; Hobday et al., 2005), and provide the opportunity test novel component technologies (Bower et al., 1997; Daneshy & Donnelly, 2004). Close working relationships with customers within projects help to facilitate the implementation of novel products by providing continual guidance to the focal firm throughout the innovation development process (Manley, 2008). Having a deep intimate knowledge of customers' activities stemming from embeddedness will improve the likelihood that a successful new product will be developed, because intimacy confers important details and tacit knowledge surrounding the customer's desires, preferences, and operations (Bohlmann et al., 2013). Embeddedness with customers allows firms to adapt to the inevitable changes in customer preferences, and thus adapt their innovation activities accordingly to improve chances of success (Barrett & Sexton, 2006; Bohlmann et al., 2013; Wagner, 2010).

However, high customer embeddedness is fraught with danger, in that it that might suppress novel innovation potential. This is because in CoPS projects, customers may tend to seek out tried-and-true technologies that have been used successfully in other projects to minimise costs and risks, therefore putting pressure toward incremental (instead of novel) improvements in technologies (Barrett & Sexton, 2006; Daneshy & Donnelly, 2004; Hardie & Newell, 2011; Keegan & Turner, 2002; Manley, 2008; Reichstein & Salter, 2006). However, these arguments are largely derived from construction industry settings, which are perhaps not as technologically dependent as oil and gas.

The role of the customers in the development of novel products for PBFs involved in CoPS like oil and gas remains likely to be a central one. This is due to customers allowing firms the opportunity to test novel component technologies within field development projects

(Bower et al., 1997; Daneshy & Donnelly, 2004). The higher levels of customer embeddedness in these situations should increase the potential for novel product innovation, particularly in the case of CoPS-related novel products, because close working relationships are required to deal with the highly idiosyncratic nature of such projects and the visionary ends they embody (Hobday, 1998). Therefore, the hypothesis is progressed that:

H2: Customer embeddedness will relate positively to novel product innovation.

7.1.3. Over-embeddedness with suppliers

In CoPS settings, close relationships with suppliers will aid firms with the integration of specialised knowledge required to develop new products (Davies & Hobday, 2005). High levels of embeddedness are a reflection of deep and close working relationships that are important to integrating complementary knowledge from suppliers in the creation of novel products in a variety of settings from manufacturing to construction (Dubois & Gadde, 2000; Tsai & Wang, 2009). Since tight integration with suppliers is a critical success factor for any firm compiling components into higher-level products including subsystems or CoPS, their increased supplier embeddedness is argued to have very low risk of adverse consequences toward novel product innovations it (Brusoni et al., 2001; Brusoni, 2005). Higher levels of supplier embeddedness should serve to increase the potential for novel product innovation since it will increase the potential value of the knowledge gained from it, since it is more likely to be incorporated into the technology development efforts. It is for these reasons that higher levels of supplier collaboration are anticipated to have positive benefits to novel product innovation; therefore the hypothesis is progressed:

H3: Supplier over-embeddedness will have a positive impact on novel product innovation.

7.1.4. Over-embeddedness with customers

Customers provide impetus and opportunity for novel product innovation in CoPS settings by setting targets and commissioning projects. In the development of CoPS-related product innovations, customers influence the progression of technology throughout the project, and embeddedness with customers helps firms to adapt innovation activities to meet shifting goals and requirements of the customers over time. However, as noted above, customers in CoPS settings can also be risk averse—demanding well-tested technologies and low costs (or at least no costly surprises attributable to novelty). As firms become more and more integrated into the these customers' innovation activities—by supporting integration, operations, and maintenance of the delivered technologies—the focal firm may lose its innovation autonomy, and become more incrementally focused on minor improvements to existing technologies being supplied to existing customers (Knudsen, 2007; Whitley, 2002). Firms may become so embedded in this customer-focused world as to effectively limit the amount of innovation information from other sources in the network (Burt, 2004; Uzzi & Spiro, 2005; Uzzi, 1997). Therefore, the hypothesis progressed here is that high levels of customer embeddedness will apply pressure and detract from the ability to introduce novel product innovations. Specifically:

H4: Customer over-embeddedness will negatively relate to novel product innovations.

7.1.5. Vertical or dual embeddedness

The interaction between suppliers and customer embeddedness has potentially deleterious effects on novel product introductions. Whitley (2002) argues rather compellingly that being highly embedded in supplier and customer networks will limit the degree of novelty that firms pursue, particularly in CoPS industries where technological change is cumulative, inter-dependent, and influenced by limited sets of customers. The argument is that firms that are embedded with both suppliers and customers have interdependent commitments to both. This limits the ability of the firm to make large technological changes, and pressures the firm toward customised, incremental solutions that are closely aligned with current product offerings. In essence, being dually embedded has the effect of locking firms into incremental technological trajectories. If firms still engage in novel innovation pursuits, this is perceived as a risk to the other network partners. It is thought to signal a disregard to the current technological progression that the firms' network partners depend upon for their activities. Therefore, pursuit of novelty tends to erode the focal firm's innovation reputation and, moreover, threatens its role position in the innovation network (Whitley, 2002).

Thus, there is a chance that increasing levels of embeddedness with customers—and with suppliers—will detract from the ability of PBFs to introduce novel product innovations. Although there are limited data in project environments specifically, customer involvement in new product development project in European manufacturing firms has been shown to impact novel product innovation performance, particularly when those products are developed via university and competitor collaborations (Knudsen, 2007). In other words, customer embeddedness may directly limit the innovation potential of the rest of the firms' collaborations. Since prior hypothesising has already noted the potential ill-effects on novelty from customer over-embeddedness (H4), and more supplier embeddedness is not suspected to detract from novelty, (H3), it is possible in this setting that customer embeddedness could reduce the positive effect of supplier embeddedness. Specifically, it is hypothesised that customer embeddedness will negatively moderate the otherwise positive relationship between supplier embeddedness and novel product innovation. Therefore, the following hypothesis is posed:

H5: Customer embeddedness will adversely moderate the relationship between supplier embeddedness and novel product innovation.

The conceptual model and hypothesised relationships for structural embeddedness is shown in Figure 14. The diagram shows the expected positive relationships between supplier embeddedness (H1), customer embeddedness (H2), supplier over-embeddedness (H3), and novel product innovation. A negative relationship to novel product innovation is expected for over-embeddedness with customers (H4). Last, customer embeddedness is expected to negatively moderate the relationship between supplier embeddedness and novel product innovation (H5).

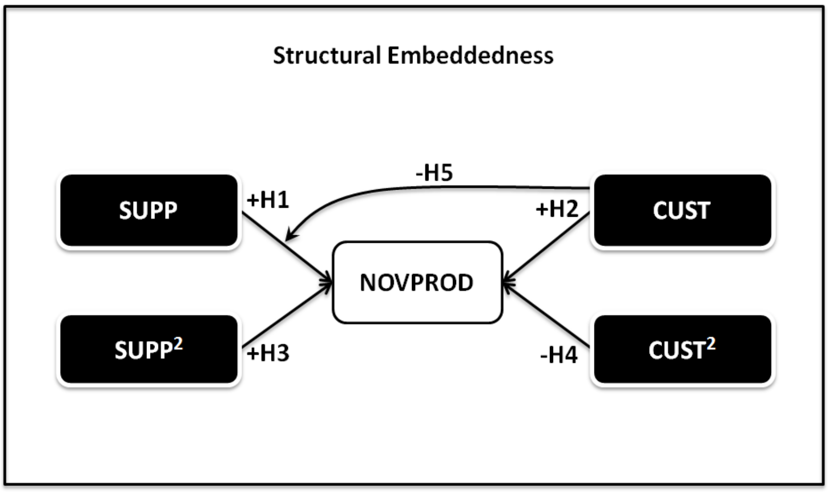

Figure 14 - Structural embeddedness conceptual model

7.2. Model testing

Eight models are necessary to conduct tests of hypotheses as summarised in Table 32. Model 1 tests the controls. Model 2 tests supplier embeddedness (H1). Model 3 tests customer embeddedness (H2). Model 4 tests supplier and customer embeddedness together (H1, H2). Model 5 tests supplier over-embeddedness (H3), Model 6 customer over-embeddedness (H4), and Model 7 tests both together (H3, H4). Model 8 tests the moderating effect of customer embeddedness on the relationship between supplier embeddedness and novel product innovation (H5).

Table 47 - Structural embeddedness regression models

	Model	1	2	3	4	5	6	7	8
	Hypotheses	controls	H1	H2	H1, H2	H3	H4	H3, 4	H5
Independent variables	SUPP		x		x	x		x	x
	SUPP2					x		x	
	CUST			x	x		x	x	x
	CUST2						x	x	
	SUPPxCUST								x
Controls	R&D	x	x	x	x	x		x	x
	LOGSIZE	x	x	x	x	x		x	x
	POC	x	x	x	x	x		x	x

7.2.1. Embeddedness bivariate correlations

The Spearman's Rho (non-parametric) correlation table is shown in Table 48. Novel product innovation has strong positive correlation with supplier embeddedness and a moderate positive relationship with customer embeddedness. The interaction term for between supplier and customer embeddedness has a positive and significant correlation with novel product innovation. Size appears to be correlated positively with both customer and supplier embeddedness, but not with novel product innovation. The sample control variable indicates that firms participating in both years are not likely to be novel product innovators.

Table 48 - Structural embeddedness bivariate correlations

Spearman's Rho		n	M	SD	1	2	3	4	5	6
1	NOVPROD	173	0.29	0.46						
2	SUPP	173	0.85	1.53	.314**					
3	CUST	173	0.56	1.29	.201**	.561**				
4	SUPPxCUST	173	1.84	6.71	.216**	.700**	.874**			
5	R&D	173	0.54	0.50	.269**	.182*	.177*	.160*		
6	LOGSIZE	173	1.78	0.92	.066	.223**	.249**	.231**	.140	
7	POC	173	1.80	0.75	-229**	-.139	-.075	-.103	.034	-.032

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

7.2.2. Embeddedness logistic regressions

Table 49 shows a summary of the model results. The models are all significant, and show relatively good fit with the data since explaining around 20 per cent of the variance in the underlying parameters per the Nagelkerke R squared measure. The control R&D is positive and significant in all the models, reflecting its central role in the ability of firms to introduce novel product innovations. POC control is significant and negative in all models, showing that panel firms (firms that participated in both years of the survey) are not likely to be novel product innovators. Model 2 shows some positive support for H1, that supplier embeddedness positively relates to novel product innovation. Model 3 shows some support for H2, that customer embeddedness supports novel product innovation. Model 4 shows that when accounting for both customer and supplier embeddedness, it is the latter that retains significance, thus supporting H1, and lessening the support for H2. Model 5 tests H3, that supplier over-embeddedness will support novel product innovation finds the opposite is true ($p < .1$, one-tailed). Model 6 does not appear to support H4, that customer over-embeddedness suppresses novel product innovation. Model 7 tests both supplier and customer over-embeddedness, and reveals even stronger evidence to reject H3. That is, supplier over-embeddedness has a marked negative impact on novel product innovation rather than a positive one as hypothesised ($p < .05$, one-tailed). Model 8 tests the interaction between customer and supplier embeddedness, finding a significant and negative reaction ($p < .1$, one-tailed).

Table 49 - Summary of embeddedness model results

Models	1	2	3	4	5	6	7	8
Hypotheses	Control	H1	H2	H1, H2	H3	H4	H3, H4	H5
	B sig‡							
SUPP		0.31 **		0.26 *	0.69 **		0.86 **	0.38 *
SUPP2					-0.08 +		-0.15 *	
CUST			0.30 *	0.08		0.30	-0.31	0.35 +
CUST2						-0.00	0.13	
SUPPxCUST								-0.08 +
R&D	1.38 ***	1.26 **	1.30 ***	1.26 **	1.21 **	1.30 ***	1.23 **	1.20 **
LOGSIZE	0.03	-0.07	-0.07	-0.08	-0.09	-0.07	-0.09	-0.12
POC	-0.78 **	-0.74 **	-0.78 **	-0.75 **	-0.71 **	-0.78 **	-0.73 **	-0.71 **
Const.	-0.41	-0.53	-0.37	-0.50	-0.65	-0.37	-0.61	-0.58
Chi-sq.	23.22	30.64	28.05	30.82	33.16	28.05	35.30	32.86
Sig.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-2 Log LL	186.6	179.2	181.8	179.0	176.7	181.8	174.5	176.9
R Sq	0.18	0.23	0.21	0.23	0.25	0.21	0.26	0.25
H&L	0.65	0.51	0.81	0.37	0.55	0.81	0.70	0.68

‡One tailed test applied to main effects variables (Mina et al., 2014)

+ (p <0.1) * (p<.05) ** (p<.01) *** (p<.001); H&L = Hosmer and Lemeshow; R Sq = Nagelkerke

Table 50 expands Model 2 showing a direct a positive relationship between supplier embeddedness and novel product innovation. The odds ratio is 1.36, meaning that as supplier embeddedness increases by one unit, the odds of novel product innovation increase by 1.36. This is significant at the $p < .05$ level (1-tailed) and the CI does not include 1, showing this is a strong positive relationship.

Table 50 - Embeddedness Model 2, H1, Suppliers

NOVPROD					95% C.I.for Exp(B)	
Variables	B	S.E.	sig ‡	Exp(B)	Lower	Upper
SUPP	0.31	0.11	**	1.36	1.08	1.70
R&D	1.26	0.40	**	3.54	1.62	7.69
LOGSIZE	-0.07	0.20		0.93	0.63	1.39
POC	-0.74	0.27	**	0.48	0.28	0.80
Constant	-0.53	0.62		0.59		
Chi-square	30.64					
Sig.	.000					
-2 Log likelihood	179.2					
Nagelkerke R Square	.231					
Hosmer and Lemeshow	.511					

‡One tailed test applied to main effects variables (Mina et al., 2014)

+ (*p* <0.1) * (*p* <.05) ** (*p* <.01) *** (*p* <.001)

Table 51 shows the detail of Model 3, which tests H2, the direct relationship of customer embeddedness to novel product innovation. There is direct support for H2, with customer embeddedness having an odds ratio of 1.34 and a CI ranging from 1.03 to 1.76 ($p < .05$).

Table 51 - Embeddedness Model 3, H2, Customers

NOVPROD					95% C.I.for Exp(B)	
Variables	B	S.E.	sig ‡	Exp(B)	Lower	Upper
CUST	0.30	0.14	*	1.34	1.03	1.76
RD(1)	1.30	0.39	***	3.69	1.71	7.94
LOGSIZE	-0.07	0.21		0.93	0.62	1.39
POC	-0.78	0.27	**	0.46	0.27	0.77
Constant	-0.37	0.62		0.69		
Chi-square	28.05					
Sig.	.000					
-2 Log likelihood	181.76					
Nagelkerke R Square	.213					
Hosmer and Lemeshow	.815					

‡One tailed test applied to main effects variables (Mina et al., 2014)

+ (*p* <0.1) * (*p* <.05) ** (*p* <.01) *** (*p* <.001)

Table 52 expands the results of Model 4. Supplier embeddedness is significant and the odds ratio [denoted Exp(B)] is 1.3, which means that as supplier embeddedness increases by one unit, the odds of novel product innovation increase by 1.3. This result directly supports H1 in that supplier embeddedness contributes to novel product innovation. However, there is no relationship between customer embeddedness and novel product innovation. Thus no support for H2 was found.

Table 52 - Embeddedness Model 4, H1 and H2, Suppliers and customers

NOVPROD					95% C.I.for Exp(B)	
Variables	B	S.E.	sig‡	Exp(B)	Lower	Upper
SUPP	0.26	0.16	*	1.30	0.95	1.77
CUST	0.08	0.19		1.08	0.75	1.56
R&D	1.26	0.40	**	3.52	1.62	7.66
LOGSIZE	-0.08	0.21		0.92	0.61	1.38
POC	-0.75	0.27	**	0.47	0.28	0.80
Constant	-0.50	0.62		0.60		
Chi-square	30.82					
Sig.	.000					
-2 Log likelihood	179.00					
Nagelkerke R Square	.232					
Hosmer and Lemeshow	.369					

‡ One tailed test applied to main effects variables (Mina et al., 2014)

+ (*p* <0.1) * (*p*<.05) ** (*p*<.01) *** (*p*<.001)

Table 53 shows the results of both embeddedness and over-embeddedness with suppliers. No support is found for H3, that supplier over-embeddedness is positively related to novel product innovation. The opposite is found. The quadratic term, which is supplier over-embeddedness, is negative and significant (odds ratio of .93). This implies that supplier over-embeddedness is curvilinear (taking an inverted U shape) and may have a negative impact on the odds of novel product innovation. Strictly speaking, as supplier over-embeddedness increases by one unit, the odds of novel product innovation decrease by .93.

Table 53 - Embeddedness Model 5, H3, Supplier over-embeddedness

NOVPROD					95% C.I.for Exp(B)	
Variables	B	S.E.	sig‡	Exp(B)	Lower	Upper
SUPP	0.69	0.29	**	2.00	1.14	3.50
SUPP2	-0.08	0.06	+	0.93	0.83	1.03
R&D	1.21	0.40	**	3.37	1.54	7.38
LOGSIZE	-0.09	0.20		0.92	0.61	1.36
POC	-0.71	0.27	**	0.49	0.29	0.83
Constant	-0.65	0.62		0.52		
Chi-square	33.16					
Sig.	.000					
-2 Log likelihood	176.66					
Nagelkerke R Square	.248					
Hosmer and Lemeshow	.546					

‡ One tailed test applied to main effects variables (Mina et al., 2014)

+ (p <0.1) * (p<.05) ** (p<.01) *** (p<.001)

To further investigate this curvilinear relationship of supplier over-embeddedness, the values of all other variables in the model were kept at the mean, and supplier embeddedness and over-embeddedness were varied across their ranges (0-9). This yields the plot in Figure 15, which indicates an inverted U relationship, starting its downward descent at around four, where the probability of introducing novel product innovation begins to diminish.

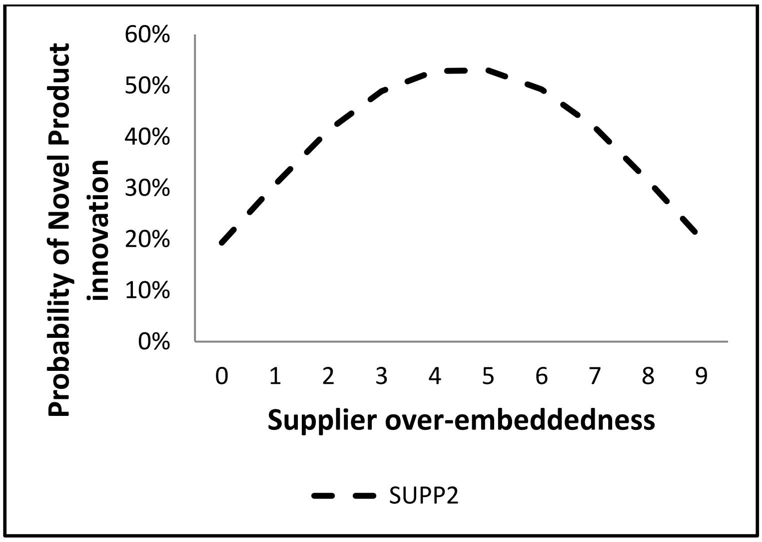

Figure 15 - Supplier over-embeddedness (Model 5)

Table 54 shows that no significant relationship was found for customer over-embeddedness (CUST2). Therefore no support found for H4, which posited that high levels of customer collaborations would negatively relate to novel product innovation.

Table 54 - Embeddedness Model 6, H4, Customer over-embeddedness

NOVPROD					95% C.I.for Exp(B)	
Variables	B	S.E.	sig‡	Exp(B)	Lower	Upper
CUST	0.30	0.34		1.35	0.69	2.64
CUST2	0.00	0.06		1.00	0.88	1.13
R&D	1.30	0.39	***	3.68	1.71	7.96
LOGSIZE	-0.07	0.21		0.93	0.62	1.39
POC	-0.78	0.27	**	0.46	0.27	0.77
Constant	-0.37	0.62		0.69		
Chi-square	28.05					
Sig.	.000					
-2 Log likelihood	181.77					
Nagelkerke R Square	.213					
Hosmer and Lemeshow	.815					

‡ One tailed test applied to main effects variables (Mina et al., 2014)

+ (*p* <0.1) * (*p*<.05) ** (*p*<.01) *** (*p*<.001)

Table 55 combines supplier and customer over-embeddedness into a single model. This model verifies the findings of prior models: that supplier embeddedness positively relates to novel product innovation, but only up to a point (i.e., the relationship is curvilinear and takes an inverted U shape). In fact, customer over-embeddedness increases in significance to the $p < .05$ level in this model. The model also confirms that neither customer embeddedness nor customer over-embeddedness appear to have a direct relationship to novel product innovation.

Table 55 - Embeddedness Model 7, H3 and H4, over-embeddedness

NOVPROD					95% C.I.for Exp(B)	
Variables	B	S.E.	sig‡	Exp(B)	Lower	Upper
SUPP	0.86	0.35	**	2.37	1.19	4.72
SUPP2	-0.15	0.08	*	0.86	0.74	1.02
CUST	-0.31	0.48		0.73	0.29	1.86
CUST2	0.13	0.13		1.14	0.89	1.47
R&D	1.23	0.40	**	3.41	1.55	7.48
LOGSIZE	-0.09	0.21		0.91		
POC	-0.73	0.27	**	0.48	0.28	0.82
Constant	-0.61	0.63		0.54	0.00	0.00
Chi-square	35.30					
Sig.	.000					
-2 Log likelihood	174.51					
Nagelkerke R Square	.263					
Hosmer and Lemeshow	.705					

‡ One tailed test applied to main effects variables (Mina et al., 2014)

+ (*p* <0.1) * (*p*<.05) ** (*p*<.01) *** (*p*<.001)

A plot of the inverted U relationship between supplier embeddedness and over-embeddedness for Model 7 is shown in Figure 16. This plot is created by holding all variables at their mean, and varying supplier embeddedness and over-embeddedness across their range. The plot suggests that, beyond three supplier relationships, the odds of introducing a novel product innovation again start to diminish. This inflection point is sooner that that revealed in Model 4.

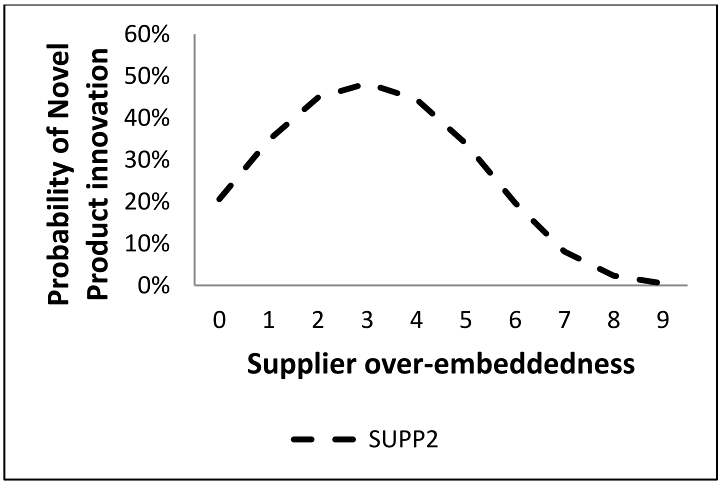

Figure 16 - Supplier over-embeddedness (Model 7)

Table 56 shows the impact of vertical embeddedness on novel product innovation (H5). Support is found for H5 because the interaction between supplier and customer embeddedness is significant with an odds ratio of .92. Thus, customer embeddedness has a negative impact on the strength of the relationship between supplier embeddedness and novel innovation. The model also indicates a positive effect of supplier embeddedness, but should be interpreted carefully. The coefficient in the interaction model means a value when the other is zero. For instance, the customer embeddedness odds ratio is positive and significant ($p < .1$), but the interpretation is the effect that this is true when supplier embeddedness is at zero. Although this latter finding provides some small support for H2, it only applies to the firms that have no supplier embeddedness whatsoever.

Table 56 - Embeddedness Model 8, H5, Customer embeddedness moderation

NOVPROD	Model 5				95% C.I.for Exp(B)	
Variables	B	S.E.	sig‡	Exp(B)	Lower	Upper
SUPP	0.38	0.18	*	1.46	1.03	2.06
CUST	0.35	0.27	+	1.42	0.84	2.42
SUPPxCUST	-0.08	0.06	+	0.92	0.83	1.04
R&D	1.20	0.40	**	3.34	1.53	7.28
LOGSIZE	-0.12	0.21		0.89	0.59	1.33
POC	-0.71	0.27	**	0.49		
Constant	-0.58	0.63		0.56		
Chi-square	32.86					
Sig.	.000					
-2 Log likelihood	176.95					
Nagelkerke R Square	.246					
Hosmer and Lemeshow	.678					

‡ One tailed test applied to main effects variables not controls (Mina et al., 2014)

+ (p <0.1) * (p<.05) ** (p<.01) *** (p<.001)

To further investigate the interaction term, a simple slopes analysis was conducted using the *Process* tool plug-in for SPSS (Hayes, 2014). The interaction effect is robust across a range of values. Specifically, the conditional effects of supplier embeddedness on novel product innovation are significant at low, mean, and high levels of customer embeddedness (one standard deviation below, at, and above the mean, respectively). According to the Johnson-Neyman test (Field, 2013), this conditional effect reduces in size from .43 to .23 when customer embeddedness goes from its lowest to its highest significant value (1.3 standard deviations above the mean). Approximately 85 per cent of the sample operates somewhere in this range of customer embeddedness according to the data. This indicates that customer embeddedness may be suppressing the potentially positive impact that supplier embeddedness could have on novel product innovation, for 85 per cent of the sample.

Figure 17 plots the interaction effect, depicting the changing probabilities of novel product innovation at high and low levels of supplier and customer embeddedness. It primarily reflects the difficulty in creating novel product innovations, since these lines all generally appear to hover around 50 per cent probability mark. However, it is the slope *differences* that are of interest. With high levels of customer embeddedness (dotted line), the probability of novel product innovation increases slowly as the firm increases its supplier embeddedness. The probability of novel product innovation increases at a much faster rate when supplier embeddedness is increased and customer embeddedness remains low (see solid line). Put slightly differently, high levels of customer embeddedness weaken the positive effect that increased supplier embeddedness has on novel product innovations.

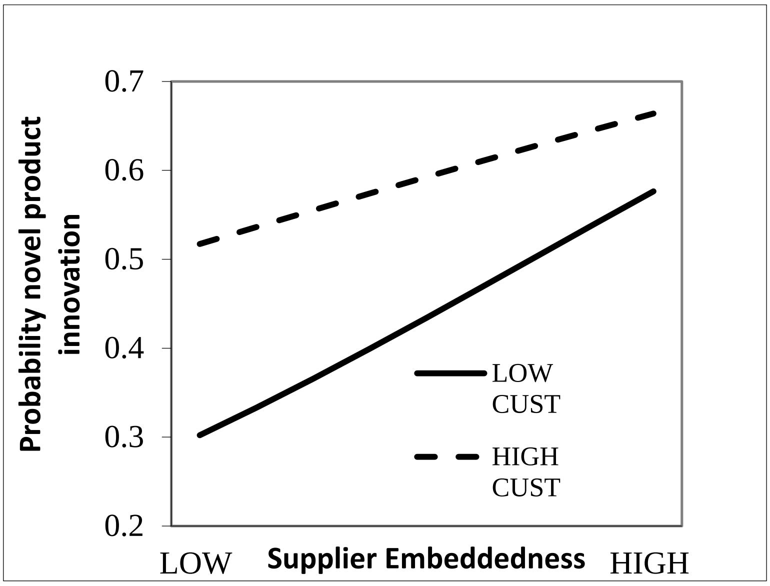

Figure 17 - Customer embeddedness moderates supplier embeddedness (Model 8)

The hypotheses and results are summarised in Table 57. This table reveals that H1 and H5 are fully supported. H2 relating to customer embeddedness is only partially supported. Test of H3, supplier over-embeddedness, is the opposite of what was hypothesised and is rejected. H4, relating to customer over-embeddedness, finds no support whatsoever and is rejected. In total, two hypotheses are fully supported, one is partially supported, and two are rejected.

Table 57 - Structural embeddedness summary of hypotheses and results

Hypothesis		Findings	Status of Hypothesis
H1	Supplier embeddedness will relate positively to novel product innovation.	Direct relationship. Odds 1.36 (p <.05)	Supported
H2	Customer embeddedness will relate positively to novel product innovation	Direct relationship found in Model 3: Odds 1.34 (p <.05). In Model 4 which includes supplier as well, direct relationship vanishes.	Partially supported
H3	Supplier over-embeddedness will have a positive impact on novel product innovation.	Curvilinear (inverted-U) relationship found. Model 4: odds .93 (p <.1), inflection point at 4. Model 7: odds .86 (p < .05) with inflection point at 3.	Rejected
H4	Customer over-embeddedness will have a negative impact on novel product innovation.	No relationship found.	Rejected
H5	Customer embeddedness will adversely moderate the relationship between supplier embeddedness and novel product innovation.	Interaction term negative and significant. Odds .92, (p <.1). Conditional effect of SUPP on novel product innovation reduces from .43 to .23 when customer embeddedness goes from its lowest to its highest significant value. This range affects 85% of sample.	Supported

7.3. Discussion

Evidence is found that supplier embeddedness has a direct positive relationship to novel product innovation. The results also clearly show that there are diminishing returns to supplier embeddedness. The probability of novel product innovations takes an inverted U shape with regard to over-embeddedness with suppliers (operationalised as the quadratic term of supplier embeddedness). The inflection point appears to be rather low, at around either 3 or 4 depending on the model. Strictly speaking, the measure is simply a proxy for determining how deeply embedded a firm is with their suppliers, hence the meaning of the units is subject to debate. Although the slope of the curve may not be significant, or the inflection point necessarily accurate (cf. Laursen & Salter, 2006), the findings suggest that supplier over-embeddedness negatively impacts the introduction of novel product innovation.

Two perspectives help to explain the curvilinear (inverted – U) relationship between supplier embeddedness and novel product innovation. First is the insight by Uzzi (1997) that redundant ties with similar firms may serve to reduce the flow of new information. If firms are deeply embedded with similar firms—in this case many suppliers—this represents a likely densely connected network. In such a closed network, information reverberates and old information is likely to resurface because of the consistent and similar types of relationships the focal firm maintains. Although it is arguable that new information is only one part of a series of activities necessary to produce a commercially viable novel product, received information that is close to its existing knowledge stocks, while easy for the firm to comprehend, might not necessarily provide unique information necessary to create novelty (Cohen & Levinthal, 1990; Dahlander & Gann, 2010).

A second explanation for the inverted U relationship is a follow-on effect from the aforementioned dense connectivity. That is, that very close-knit networks may cause firms to discount or ignore the information that is outside of their current thinking, even it does manage to infiltrate the network (Uzzi & Spiro, 2005). As Skilton and Dooley (2010) argue, repeat collaborations promote shared mental models, which in turn stifle the creativity necessary to produce novel outcomes. This is because ‘creative abrasion’ (idea generation, closure/advocacy, and conversion processes) is suppressed by repeated collaborations, because project members will be less likely to break from established mental and structural models that have been brought about through repetition.

No strong support was found for the hypothesis that customer embeddedness positively relates to novel product innovation. Only in the case where the firm has no supplier embeddedness at all (a highly unlikely situation), does customer embeddedness positively relate to novel innovation outcomes. In all models that include supplier embeddedness this effect disappears. A potential reason why customer embeddedness does not relate to novel products is that customers are often risk-averse toward novel innovation. In construction industries in particular, customers are strongly reputed for seeking low-risk solutions (Barrett & Sexton, 2006; Daneshy & Donnelly, 2004; Hardie & Newell, 2011) and often view novel innovation as a risk factor to be avoided (Keegan & Turner, 2002). If these assertions hold true in this research setting, it is not surprising then that customers are not (either positively or negatively) related to novel product innovations because they simply do not influence these outcomes. Instead, customers are busy driving incremental innovation outcomes. Further supporting this assertion is the robust positive role that supplier embeddedness plays in novel product innovations. Supplier embeddedness does relate to novel product when tested in isolation, and in the presence of customer embeddedness. Therefore, customers simply do not play an important role in novel product innovation because innovation comes from the bottom up—from suppliers.

It was also found that being vertically embedded with both suppliers and customers has potentially negative consequences upon novel product innovation. Specifically, customer embeddedness adversely moderates the relationship between supplier embeddedness and novel product innovations. This finding lends empirical support to theoretical arguments that very high levels of direct collaborative involvement might lock firms into specific or incremental technological trajectories (Whitley, 2002). Whitley (2002) argues that high levels of network embeddedness, specifically with suppliers and customers, may diminish novel innovation activities because it would mean the firm must depart from the stable industry technological trajectory, and in turn affecting the firms' innovation role in that network. Such disruption signals to other partners that the focal firm may be an unreliable partner, because the normal incremental pace of change is disrupted by novel innovation. Hence the argument remains that firms with high embeddedness are likely to maintain stable incremental trajectories. The finding on vertical embeddedness also relates to path dependency and lock-in (Arthur, 1989, 1990). Manning and Sydow (2011) speak of lock-in as it applies to project networks, arguing that collaborations are, like technologies, on trajectories established by a combination of historical choices (and sometimes chance occurrence), and reinforced positive feedback. For instance, German TV show project teams display highly path-dependent collaboration patterns (Manning and Sydow, 2011). The effect of being locked into deep collaboration, may adversely impact upon innovation since it may severely limit managerial choice (Schreyogg & Sydow, 2011).

7.4. Chapter summary

In sum, this chapter shows that novel product innovation is clearly related to inter-organisational relationships with suppliers. Since the sample includes a wide range of firms, it implies that project-based firms look down their supply chain for novelty. System integrators look to their contractors, and contractors to their suppliers, and so on, in order to introduce novel product innovations. There are limits however, and too much supplier embeddedness can detract from novelty. The lack of any compelling findings relative to customer embeddedness reveals that novel products may be driven entirely (causality is not claimed due to the research methods) by the lower tier actors. This means, in this context, customer or client-led innovation is not prevalent. In fact, too much customer embeddedness appears to lessen the positive effect that supplier collaborations do have. A more in-depth discussion of the contributions implications of this study are presented in Chapter 8.

CHAPTER 8: SUMMARY AND CONCLUSION

This thesis sought to explain how PBFs develop novel product innovations—those that are new to the industry—in environments where inter-dependent firms work together to deliver complex system-level outcomes. This thesis defined a 'CoPS-related novel product' as 'an artefact, component, sub-system, complex product system (CoPS), or combination thereof that constitutes a technologically new—or significantly improved—physical product / technology, that is both new to the firm and new to the industry.

Three specific challenges that face PBFs in their development of CoPS-related novel products were identified. The first challenge is that PBFs are limited to contingent opportunities for innovation tied to the projects in which they participate. A particular concern is how PBFs capitalise on opportunities that arise unexpectedly and that cannot be foretold. The second challenge is how PBFs resolve technological interdependencies between their novel products and the inter-reliant technologies existing within the project-based productive network. This is an important problem because different organisations contribute to the hierarchy of artefacts, components, subsystems, CoPS, and interlinked CoPS (system of systems) that comprise the technology in the industry—and any of these can locus for a 'CoPs-related novel product'. The third challenge relates to the enduring inter-organisational relationships that PBFs maintain, which is called structural embeddedness. Structural embeddedness theoretically supports novel product innovation by engendering trust and mutual understanding; however, being overly committed to them might have the opposite effect, limiting firms to incremental—rather than novel—innovations. Specifically important to novel products is how embeddedness with suppliers and customers, and both in tandem, impacts the probability of introducing a novel product innovation.

Three studies were conducted to investigate these three challenges. The first study focused on firm-level capabilities that enable firms to capitalise and convert contingent opportunities into novel products. The second study focused on the use of open innovation, particularly non-pecuniary forms, to resolve technological interdependencies. The third study looked at structural embeddedness based on a new proxy measure derived from formal collaboration patterns to facilitate a better understanding of how enduring relationships affect novel product innovation.

The findings of these three studies are recapped briefly here to serve as a starting point for a higher-level integrated discussion of the findings presented in this final chapter. First, it appears that contingent opportunities for innovation are addressed through two firm-level capabilities—*adaptive problem solving* within projects and *networking* with partners.

These capabilities work in combination to deliver novel products. That is, problem solving capabilities directly relate to novel products, and they most likely operate through firms' networking capabilities, as shown by the results of the tests for mediation. Second, to resolve technological interdependencies, it appears that firms engage in specific patterns of non-pecuniary open innovation activities, including a narrow focus on inbound knowledge sources and a practice of revealing details of innovations to customers and network partners. Revealing is believed to be a developmental step in the innovation process that solicits feedback from network partners, which is used in subsequent refinement of novel products via firms' internal R&D activities. This stepwise approach appears to support novel product innovation in the non-pecuniary outbound form. Third, it appears that increasing structural embeddedness with suppliers supports novel product innovation, but only up to a point where it may detract. While there is no direct relationship with customer embeddedness, it may suppress the positive effect of supplier embeddedness on novel product innovation. Individually, these findings answer the three research sub-questions, and provide insights into mechanisms that are useful (or detrimental) to novel product innovation efforts of PBFs.

But the individual studies in isolation are not as insightful as when their results are viewed in aggregate. At a higher level, the studies paint a more detailed theoretical picture of how PBFs navigate the waters of intensely project-based environment—especially the very interdependent network obligations this represents—and still deliver novel products. Rather than rehashing the individual findings of the individual studies, which were discussed in each of the relevant chapters, a primary focus of this chapter is to integrate the individual findings into a higher-level theoretical narrative on the phenomenon of novel product innovation in PBFs. To support this focus, the chapter is organised into six sections. The first section synthesises the results of the studies by developing cross-cutting, theoretically-driven themes on novel product innovation in PBFs. It establishes a theoretical narrative of how PBFs deliver novel product innovations and, in so doing, provides a succinct summary of theoretical implications of the research. The second section discusses contributions to the theories that were drawn upon in the establishment of arguments and hypotheses. The third section discusses the practical implications of the research. The fourth section details several limitations. The fifth suggests avenues for future research. A sixth section concludes the chapter and the thesis.

8.1. New theoretical perspectives on novel product innovation in PBFs

Analysis and discussion prior to this section has remained focused on the specific challenges facing PBFs through the research sub-questions and their three related studies.

This section seeks to bring the discussion up a level, to view in aggregate how the individual study results help to answer the central research question: *What factors facilitate PBFs' ability to introduce novel product innovations in environments where interdependent firms deliver complex system-level outcomes?*. In this vein, this section presents an integrated synopsis of the research findings and develops three cross-cutting themes. These themes are supported by findings from multiple studies and help to elucidate a richer understanding of the factors that contribute to novel product innovation in PBFs. These cross-cutting themes provide a more robust explanation than any study in isolation can.

To aid in the development of an integrated synopsis of findings, a Venn diagram (See Figure 18) was created, comprised of three overlapping circles with the constructs and relationships from the thesis mapped upon it. The first is 'Focal PBF', which represents the unit of analysis of the thesis. The second is 'Projects', to represent the project-based environment that PBFs operate within. The third is 'Networks', representing the project-based productive networks within which PBFs operate. These categories are not mutually exclusive, as has been argued exhaustively herein; PBFs are inextricably tied to industry projects and are also part of a latent network of firms that comprises all project-based industries (Gann & Salter, 2000). The overlapping nature of these circles, though notional, is grounded in what we know as the PBFs' industrial environment, particularly with regard to CoPS (Gann & Salter, 2000). Within this Venn diagram, the reader will find the thesis constructs with direct or indirect relationships, shown to be statistically significant in the three studies, with novel product innovation. This mapping exercise is a way to visualise the relationships in space, in an effort to facilitate a more nuanced discussion of findings.

An important point to make is regarding the location of novel product innovation—the outcome variable of interest that resides in the intersection of PBFs, projects and networks. It is placed here because it represents an output of the PBF, introduced to meet the demands of industry projects and to simultaneously meet the needs of network partners. The location of novel products clearly reflects the notion of the project-based productive network and the fact that innovation is a collective endeavour aimed at solving industry-related challenges posed by the projects that network partners are engaging in (Gann & Salter, 1998, 2000; Gann, 2000).

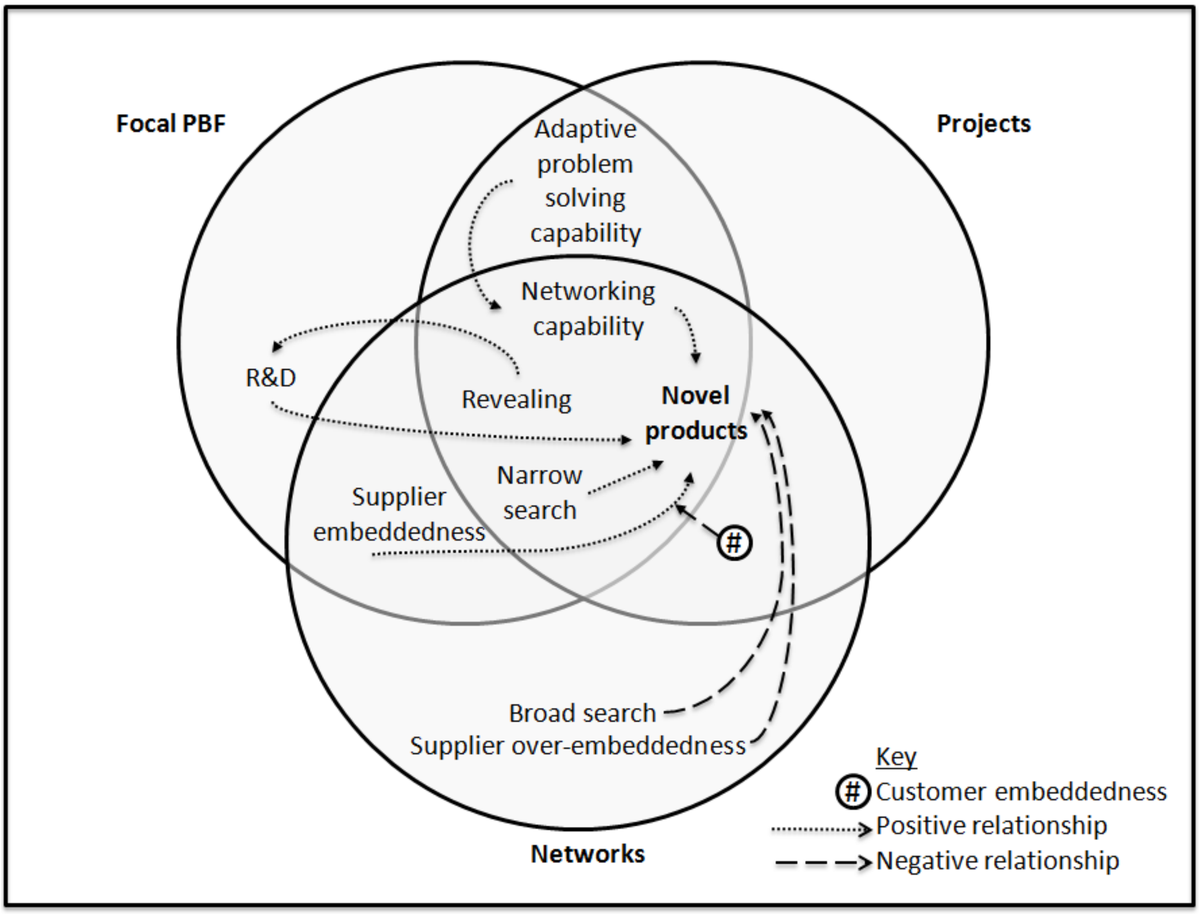

Figure 18 - Diagrammatical synopsis of findings

The first cross-cutting insight is that novel product innovations are the result of firm-level mechanisms that operate at the intersection of projects, networks, and the PBF. Although this notion is not new (Gann & Salter, 2000), the findings reveal three specific mechanisms that help explain the phenomenon. The three mechanisms are networking capabilities, revealing (sharing) details of innovations, and a narrow or focused search for innovation information. There are theoretical arguments for their close proximity to each other, and support for the notion that that these may actually be complementary activities. Thus, revealing, searching, and networking may collectively aid in the creation and commercialisation of novel product innovations. The next few paragraphs describe their location on the diagram and then discuss how these constructs may actually work in tandem. A summary of all the cross-cutting relationships is shown in Table 58.

Table 58 - Themes

	Theme	Study 1: **Capabilities** *to capitalise on contingent opportunities*	Study 2: **Open Innovation** *to resolve technological interdependencies*	Study 3: **Structural Embeddedness** *to understand impact of enduring relationships*
		Support for themes from each study		
1	Novel product innovations are most strongly supported by firm-level mechanisms that operate at the intersection of projects, networks, and the PBF	• Strong direct relationship between networking and novel product innovation. • Networking capability fully moderates firms' problem solving (i.e., PBFs use problems as an impetus, but networking is necessary to fully realise novel products).	• Revealing technological details to network partners solicits feedback, which is used to refine R&D and produce novel products. • Narrow search patterns may be tied to improvements relative to existing technology, as well as to support the refinement of technology per the feedback received from revealing activities.	
2	Excessive commitment levels may detract from novel product innovation		• High levels of sourcing (broad search) are negatively related to novel products innovation, and may be more likely related to incremental innovations.	• There are detrimental effects of supplier over-embeddedness to novel product innovations • 'Dual embeddedness' is negative in that customer embeddedness suppresses the positive contribution of supplier embeddedness.
3	Information for novel product innovation is brought into the firm in a formal and structured manner		• Low levels of sourcing (narrow search) represents focused attention to useful sources of information that are helpful to create novel products.	• Supplier embeddedness has a positive relationship with novel product innovations.

Networking capabilities play a central role in the innovation process for PBFs because they represent an ability to create technology that is ultimately used in projects by network partners. To rehash, the networking construct is comprised of elements of technological breadth, supply chain management, and leveraging network and partnership arrangements. These activities are core to firms' ability to integrate disparate knowledge sets surrounding various technological components and subsystems, and combine them into products used in industry projects. The centrality of this capability for PBFs is further exhibited by the way it fully moderates the relationship between adaptive problem solving and novel product innovation. Adaptive problem-solving capability is comprised of adapting to changing circumstances, resolving problems, and drawing from past experiences—all in the context of industry projects. This capability resides in the overlap between projects and PBFs, and it operates through the more centrally placed networking capability. Problems move from the more peripheral interface to the centre. PBFs that undertake problem-solving activity within projects gives rise to a more central activity of networking. The PBF works directly with network partners in the context of the project (Manley, 2008) —and it is the confluence of these events that gives rise to novel products.

Found close to networking capabilities are the non-pecuniary open innovation constructs. Revealing divulges innovation information—from the focal firm to network partners, all in the context of projects—and thus is something that also occurs at the intersection of all three circles. Revealing solicits feedback from network partners. This feedback travels back into the PBF for refinement via the firms' R&D activities. After this, the novel product, which is used in projects and by others in the project network, is introduced (Dahlander & Gann, 2010; Henkel et al., 2013). Additionally, narrow search is positively related[9] to novel products. Narrow search invokes notions of search patterns residing closer to the existing activities of the firm and in close proximity to existing knowledge sets (Helfat, 1994; Levinthal & March, 1993; Wang, Rodan, Fruin, & Xu, 2014). Hence, narrow search also resides in the diagram at the intersection of the three circles, near the nexus of current state of technological knowledge as embodied in current projects and network architectures.

Viewing these three constructs in close proximity to each other may provide a more nuanced understanding of novel product innovation. For instance, narrow search may be a complement to revealing activities. Revealing information about novel product innovations would tend to create a knowledge-rich environment for other firms. In such an environment, these other firms would not need to search broadly for innovation information related to the collective challenges (Garriga et al., 2013). The supposition is that revealing results in narrower search patterns because firms are aligned with the collective problems that the industry is trying to solve. Revealing information about novel products means that collective

[9] Although non-pecuniary inbound sourcing (operationalised as broad search) is negatively related to novel products, it is important to remember that the opposite is true as well.

problems are known to most players. The resulting search for knowledge is therefore likely to be narrow, because it is adjacent to the dominant designs that characterise the technological base of the industry (Henderson & Clark, 1990; Sidhu et al., 2007). PBFs may reveal to solicit feedback from network partners, and may conduct narrow search as part of the technology refinement process that occurs through internal R&D processes; therefore this is a highly interactive process. The close proximity of these non-pecuniary knowledge flows to networking may mean that this capability may also be necessary to explain how knowledge flows are synthesised into innovations. Certainly, the idea of technological breadth (Prencipe, 2000), one of the core elements in the networking construct, reflects this notion of PBFs being able to integrate disparate knowledge sets regarding new product development.

The second cross-cutting theme is that excessive commitments may detract from novel product innovation. Looking at the bottom of the diagram in the ‘networks’ circle are broad search and supplier over-embeddedness, which are both negatively related to novel product innovations. Broad search is depicted on the diagram as something that occurs far from the PBF and deep inside the network, as the firm searches widely for information from existing information channels to support innovation activities (Laursen & Salter, 2006). Similarly, supplier over-embeddedness is depicted as occurring deep inside the network as the firm extends its connections deep into a number of supplier relationships. Another finding is the adverse impact of customer embeddedness on supplier embeddedness, which is considered to mean that the firm is dually embedded. Each of these is discussed next in terms of how they represent over-extensions of the firm that may detract from novel product innovation.

Although increasing levels of search have been shown in manufacturing firms to have potential curvilinear (inverted U) relationship with innovation performance (Laursen & Salter, 2006), in this study broad search in general seems (linearly) detrimental to innovation performance. Laursen and Salter (2006) argue that managerial attention may be to blame for the curvilinear effect, as managers do not have the bandwidth to adequately assess the quality and usefulness of such varied and voluminous information flows (Ocasio, 1997). While managerial attention theory is one potential explanation, there are several additional reasons that may explain the linear negative effect exhibited by PBFs relating to project-based organising constraints. For instance, PBFs are often limited in terms of slack resources, including staff and budget (Keegan & Turner, 2002; Lampert & Semadeni, 2010). PBFs may also lack time to engage in activities that are not directly focused on project-related tasks (Bakker, 2010; Goodman & Goodman, 1976). Together, a lack of resources, budget, and time may detract from the ability to search broadly at all. PBFs are constantly conducting projects and solving technology-related problems in that context. Those PBFs that do manage to search broadly necessarily reallocate resources that may be better spent on focusing on the known collective problems associated with current technological trajectory in order to innovate in novel ways. By focusing attention elsewhere, PBFs searching broadly would not be collecting information that lies in close proximity to existing knowledge sets. Therefore, broad searching takes firms' focus away from the current technology trajectory and collective industry problems that this trajectory represents. Since attention to these problems is necessary to innovate within the stable technological trajectories in CoPS industries (Whitley, 2002), firms that search broadly are not close enough to these problems to contribute. In addition, the ability to innovate within current projects is likely degraded further when scarce resources are assigned to broad search rather than to solving current problems.

Similarly, over-embeddedness with suppliers and dual embeddedness (the finding that customer embeddedness detracts from the positive effect of supplier embeddedness) both represent structural relationships that inhibit the introduction of novel products. These structural attributes are argued here to be reflective of excessive commitments of the firm. The findings suggest that embeddedness levels with suppliers above three or four begin to have a deleterious impact on novel product innovation. And, although some supplier embeddedness is good, customers may suppress that positive relationship. A compelling argument for these findings is from Whitley (2002), who argues that being too highly embedded with suppliers and customers helps to ensure that the firm does not stray far from the current technological trajectory, and may likely force the firm into an incremental innovation trajectory (if anything at all). Whereas focused search patterns close to the current technological trajectory (narrow search) was argued to support novelty, the deep commitments to suppliers and customers may physically limit the firm from moving against the stable technological trajectory in novel ways. Further, when firms are overly tied to suppliers, they may become completely dependent on them for technology, and thus for the focal firm, innovation becomes very path dependent, and inertia sets in locking the firm into specific technology paradigms associated with the current technological trajectory (Arthur, 1989, 1990). Manning and Sydow (2011) argue that like technology, firms' network relationship patterns also have stable trajectories that are continually reinforced by positive feedback via repeated inter-organisational collaborations over time. In so far as innovation goes, the effect of being locked into deep extensive relationships with network partners would tend to limit managerial choices relative to considering any alternative pathways

(Schreyogg & Sydow, 2011). The result of high levels of structural embeddedness is that it would limit the PBFs' room to manoeuvre (Schreyogg & Sydow, 2011). Further, PBFs may have actually have disincentives to pursue novel innovation because of reputations associated with being a reliable—that is, incremental—technology provider (Whitley, 2002). Customers, in particular, may exhibit a strong preference for reliable technology that is well-tested in other settings (Barrett & Sexton, 2006; Keegan & Turner, 2002). Going against this trend might be detrimental to the technological role position and associated reputation of the PBF (Whitley, 2002).

In total, the argument that excessive commitments detract from novelty exhibits the features of a paradox. While broad search takes the firm away from the nexus of problem solving which is in close (knowledge) proximity to existing technologies and thereby limiting the ability to contribute to common problems, high levels of structural embeddedness anchor the firm so strongly the existing technology base that incrementalism is almost assured. They therefore represent two potential pathways away from novel products, and either may be a cause for concern, depending on the specific circumstances of the firm.

The third theme is that information supporting novel product innovation is brought into the firm in a structured manner. It was found that structural embeddedness, in the form of formal supplier relationships, is positively related to novel product innovations. This indicates that formal knowledge conduits matter. This thesis operationalised embeddedness based on formal collaboration patterns. The construct includes a wide range of collaboration modes, including co-development of technology, but also including less technically-oriented collaborations like the consolidation of supply chains and managerial training. Increased levels of collaboration with suppliers across these modes indicate increased levels of structural embeddedness. It shows by proxy how reliant the firm is upon these formal external connections. It can be speculated that supplier embeddedness gives rise to novel products because collaborative relationships increase the opportunities for knowledge sharing, and thus may lead the firm to novel combinations of information leading to subsequent product innovations. Knowledge can be shared in all formal collaborative encounters and thus, regardless of the specific intent, all collaborations would have potential for information sharing that might serve as a locus for innovation, even if only the initial idea is incubated there. The most important factor is to realise that knowledge obtained via this method is intentional and formalised at the organisational level. Formal collaborations are sanctioned activities built upon purposeful interactions with other firms. In light of the interdependent nature of innovation for PBFs, this mechanism seems to make logical sense in terms of how it contributes to novel product innovation. Formal interface with suppliers as a locus of new product innovation also seems to help resolve an issue that PBFs face: novel product innovations must be relevant to the extant technological trajectory in the industry. Supplier collaborations would facilitate such relevant products because of their condition of being purveyors of components and subsystems that are industry-specific, and thus they are well versed in these trends (Gann & Salter, 2000).

Contrast this embeddedness finding to the finding in Study 2 that sourcing is negatively related to novel products. The specific operationalisation of sourcing is based on the precept of innovative search, which still looms large in contemporary literature on open innovation (Laursen & Salter, 2006, 2014). Study 2 found that broad search is negatively related (and, alternatively, that narrow search is positively related) to the introduction of novel products. One reason for this may lie in the less-structured origins of the search construct. The origin of search rests in the behavioural theory of the firm, and one impetus for engaging in search is in response to missing performance expectations at the firm level (Greve, 2003; March, 1963). Search represents an effort to find information that will support the development of new products (March, 1991). When this search is triggered to solve a problem, it is termed problemistic search (Greve, 2003). Broad problemistic search is often related to novel products because it increases the chances that a novel combination of information will be found (Leiponen & Helfat, 2010). But as Study 2 shows, project-based firms that produce novel products search narrowly, not broadly,[10] indicating a more structured nature of knowledge gathering that reinforces the notion of interdependency.

When both findings are combined, structured embeddedness with suppliers and narrow search support novel product innovations, it provides some compelling support for the argument that formal information pathways are most important for project-based firms. Formal collaborations are premeditated. In the context of project-based organising, use of premeditated and formalised sources of knowledge also reflects general stability of the latent network. Searching broadly, on the other hand, is less premeditated and more haphazard, in that the firm looks anywhere it can for innovation information. Broad search, particularly if it is the problemistic type discussed in the original literature, can therefore be considered more reactionary. Narrow search, on the other hand, reflects some certainty about the location of innovation information; thus it is in line with the theorised interdependent nature of

[10] It is worth reiterating here for the sake of comprehensiveness that the complimentary construct of search depth (Laursen & Salter, 2006) was tested and was found to have no relationship to novel product innovation when substituted for search breadth.

innovation in project-based settings. If the firm does plan to do something novel, doing so without at least some coordination of their network partners would not be a good strategy, to say the very least.

8.2. Contributions to theory

In addition to the new theoretical perspective on novel product innovation in PBFs, the findings of the thesis also contribute insights into the original theories that were drawn upon. Each of the three studies provides some new insights back to the underlying theoretical notions that helped to build the argument structure and hypothesise relationships in the first place. The contributions are perhaps specific to the context of the thesis, but nonetheless provide some new guidance to researchers as to the usefulness and generalisability of extant theory.

A primary contribution of the thesis is toward improving our understanding of project-based productive networks, which are large webs of inter-connected firms that collectively facilitate the conduct of projects and development of innovation (Gann & Salter, 2000). These networks can be sufficiently large. For instance, very large engineering and construction large projects typically involve tens of thousands of individual firms (Davies, Gann, & Douglas, 2009). To directly observe such a network, in particular the ties between firms, represents an intractable problem. The thesis represents a methodological approach to overcoming the challenge of directly observing large networks. Specifically, this thesis argues that cross-sectional survey of a representative sample of firms operating inside the project network is one way around this challenge. This approach hinges upon first identifying a suitable project-based productive network, and second, garnering a representative sample of firms from it. On the first point, this thesis targeted upstream oil and gas, which is project-based since it is focused on constructing capital assets to produce oil and gas. On the second point, a representative sample of firms was identified by collaboration with the leading industry trade group for upstream oil and gas in Australia. With their help, a sample of project-based firms that represented a large portion of the industry was identified. Once these hurdles were overcome, standard statistical analyses were used to identify patterns of relationships between variables. These relationships help to show the specific mechanisms that relate to the introduction of novel product innovations for PBFs. In aggregate, they indirectly help show how the project-based productive network operates.

Specific contributions to theories that support each study follow. In Study 1, Capabilities, the argument was made that ordinary capabilities augmented with ad hoc problem solving would be the most appropriate approach for PBFs to develop novel product innovations. Since much of the strategic management literature focuses on the role of dynamic capabilities in driving novelty at the firm level, the ordinary capability and ad hoc problem solving argument represents a departure from most of the mainstream literature on capabilities. PBFs are resource limited, and opportunistic in their innovation activities. As a rule, opportunities for innovation are episodic. In many CoPS industries, technology tends to change slowly and incrementally, punctuated infrequently by market or structural shifts that allow novel innovations to be pursued. Winter (2003) makes the argument that in such slow-paced environments, it does not make fiscal sense to carry the costs of a higher level change-oriented dynamic capability routine (in this case novel product innovation routines) when ordinary capabilities associated with the more static position of the firm relative to others can serve as a base, and ad hoc problem-solving activities can help to deal with the unexpected shifts. Indeed, the results of the study show that a version of ad hoc problem solving which is related to project-based tasks is indeed an ability that PBFs exercise, and further, that this problem solving operates in conjunction with ordinary networking capabilities reflecting PBFs' more static positional role as a technology provider and network partner (i.e., a stable actor in the project-based productive network described by Gann and Salter (2000)). The findings call into question the applicability of dynamic capabilities—that which dominates the strategic management literature —to CoPS settings including upstream oil and gas and other engineering-intense construction industries. The findings suggest that the capabilities underpinning mutual adjustments exemplified by PBFs through activities like ad hoc problem solving are not the same as the dynamic change-oriented routines that are firm-centric and displayed by firms in high-velocity settings. Further, dynamic capabilities may be particularly hard to justify in settings where firms are highly interdependent in their innovation activities as PBFs are. In these firms, mutual adjustment is required to meet changing circumstances in projects. This is why problem solving only results in novel product innovation if it operates through the standard networking capabilities that allow PBFs to successfully leverage their networks in order to introduce the novel product. At an even more basic level, networking capabilities reflect the ordinary capabilities that are necessary to play a technologically relevant role in the network.

Study 2 contributes back to the open innovation literature in two ways. First, the variables used to operationalise non-pecuniary outbound open innovation (revealing) provide signposts to other researchers wishing to investigate this phenomenon. This thesis differentiated between two types of revealing, including open sharing, which is free revealing of technical detail to others, and closed sharing, which is technical detail shared under confidentiality. It is apparent from the findings that these activities are highly relevant to novel product innovators in this particular setting. These factors can be used as the basis for a more detailed scale development in future research and to support subsequent testing in other settings. The second contribution regards the use of broad search (Laursen & Salter, 2006) as the operationalisation of non-pecuniary inbound open innovation (sourcing). The findings are quite contradictory to the corpus of knowledge about the positive effects of search on innovation performance (Chen, Chen, & Vanhaverbeke, 2011; Chiang & Hung, 2010; Laursen & Salter, 2006). Much of the empirical study on the subject is on manufacturing firms, and findings of this thesis suggest that firms operating in network environments to deliver integrated technological products search narrowly. Therefore, the findings suggest that broad search may not be as valuable a tool for innovation in networked environments. Instead, narrow search may be a reflection of local search closely tied to existing technology. This focus on current technology is a requirement of collective technological progress that PBFs participate in (Whitley, 2002) as firms focus on innovations that closely relate to the current state of technology and its trajectory sets (Helfat, 1994; Levinthal & March, 1993; Wang et al., 2014). The findings call into question the generalisability of the popularised search construct based on survey data first argued by Laursen & Salter (2006), and provide the basis for a call for researchers to investigate alternative modes of inbound information flows that may be more useful in network environments like the ones in which PBFs operate.

Study 3 contributes much-needed clarity to the concept of structural embeddedness for firms operating in project-based productive networks, and proxy measures for these networks that are likely too large to measure directly. The idea of inter-organisational (structural) embeddedness is drawn from the social capital literature (Granovetter, 1985; Uzzi, 1997), where it has a specific meaning derived from the actual structure of collaborative networks (Rowley, Behrens, & Krackhardt, 2000). However, the project literature does not so clearly define structural embeddedness, defining it as the number of shared third-party connections (Jones and Lichtenstein, 2008), and more often loosely referring to this phenomenon as firms repeatedly collaborating in projects over time (Bakker, Knoben, de Vries, & Oerlemans, 2011; Jones, Hesterly, & Borgatti, 1997) or only referred to implicitly in terms of a latent network structure (Gann & Salter, 2000). Project-related literature thus does not provide good definitions or measures to assess structural embeddedness. Further, directly observing the actual large networks poses an intractable problem because they contain thousands of firms (Davies et al., 2009). Therefore, this thesis established a method to measure structural embeddedness using survey data and statistical analysis instead of direct observation. Specifically, the breadth of formal collaborations a firm maintains was used as a proxy for structural embeddedness. This focuses upon relationships that are strategic choices made by firms to maintain collaborative ties (Bakker et al., 2011; Bakker, 2010; Manning & Sydow, 2011). The operationalisation is patterned after the construct of *regional embeddedness* used in the economic geography literature that focuses on the location of collaborations (in country or abroad) often used to test their relationship between embeddedness and innovation success (Collinson & Wang, 2012; Love, Roper, & Hewitt-Dundas, 2010; Song, Asakawa, & Chu, 2011).

The benefits of this proxy approach are manifold. Formal collaboration patterns are not necessarily directly related to projects. In this vein the measure developed herein allows insights to be gained into the latent network structure (which persists in the background of projects), which is comprised of the many inter-organisational relationships that PBFs maintain with each other. This insight into the latent network structure is the important attribute that allows inferences to be made about how an industry's projects are supported. A further advantage to scholars is that the construct is based on a pedigree of well-established innovation survey instruments based on the OECD's Oslo manual (2005). Therefore, researchers can adopt this same approach on other representative samples to yield probabilistic relationships of structural embeddedness to well-defined outcomes like novel product innovation, used here.

8.3. Practical implications

Managers of project-based firms seeking to develop novel products need to focus first on the internal capacity to adapt to changing circumstances in projects. With the inherent uncertainties that large projects pose, shifting circumstances will present opportunities to innovate. Adapting to these changes requires a problem-solving attitude that prioritises innovation. In this regard, it is also important to transfer lessons learned from past projects to spur this problem-solving innovation process.

But problem solving is not enough to produce novel products. Firms must also use their network partners, including supply chain structures, and their existing breadth of technological offerings. Together, these form a networking capability that enables the firm to translate outcomes of the problem-solving activity into novel products. In this regard, it is likely that the network partners represent both sources of knowledge for developing innovations, and also are potential adopters of the product.

Novel product innovator firms adopt a comprehensive technology-management strategy that is aligned to their broader context and is responsive to the collective needs of customers and the industry. With the increasing pressures to open up their innovations practices, firms have many options. An obvious form of engagement is to step up outbound activities like patenting and licensing to capture value from the finished products, or to expand the possible paths to market. An important but perhaps underutilised strategy is to selectively reveal details of innovations without any prospect of immediate monetary benefit. In a project environment where network partners are important in the development *and* diffusion of innovations, this type of outbound activity helps to ensure that novel product innovations under development meet the expectations of customers. In practice, revealing means engaging in non-disclosure agreements, but also includes more open forums. Revealing in this way solicits feedback from partners and customers that is useful to the novel product-development process.

It is important to realise, however, that simply revealing innovation information is not enough. It must be followed up by subsequent development activities. That is, once information is revealed, and the customer and network provide their feedback, it is necessary to incorporate it into the development process. Therefore, revealing activities must be complimented by an internal capacity to integrate and transform the information that is obtained from the network (a so-called absorptive capacity). This capacity could exist in the internal R&D department, but a dedicated set of resources could be tasked for soliciting and integrating feedback from clients, collaborations, and other potential adopters. In practice, this could mean a market-facing commercialisation team, or applied R&D team with a market-facing function. The goal in this process is to integrate the feedback that is prompted by the act of revealing and, in turn, develop a better product.

Managers should take solace in the finding that some deep relationships with network partners can indeed provide positive benefits to novel product innovation. Supplier embeddedness in particular is positive, but there is a danger in becoming over-embedded with them, as too much can deter from novel product innovation. Moreover, customer embeddedness suppresses the positive benefit of supplier collaborations. That is, customers lessen the positive effect that suppliers bring.

The suspected deleterious mechanism in both cases is that over-embeddedness, or vertical embeddedness, locks firms into incremental innovation trajectories. This is because the firm has a very dense network. In these cases, the firm is beholden to its suppliers in terms of the products it receives, and to its customers in terms of the products it tries to sell. These constraints make it hard for the firm to break out of the incremental technological progression by creating novel innovations. In fact, firms may be disincentivised to innovate outside of the normal incremental trajectory because of these connections. If the firm does choose to produce a novel innovation, it runs the danger of being viewed as a risky partner (Whitley, 2002), and in a project environment, this can be detrimental to long-term survival if it begins to endanger the steady pipeline of future project collaborations.

The implication for managers is that they should choose wisely in terms of the number of external firms they tie themselves to. Although there is no correct number, flexibility with chosen firms may help avoid the ill effects on innovation associated with having too many similar collaborators. Managers should not allow any particular external partner to hold too much sway in the innovation processes. This would serve to limit the thinking-involving innovation by focusing on what is, rather than on what is possible. In effect, over-embeddedness provides managers with recycled information, and effectively drowns out new ideas. Managers should introduce diversity and flexibility into the selection criteria for collaboration partners, and regularly reassess these choices during the innovation process.

8.4. Limitations

8.4.1. Generalisability

As with other single industry studies (Ahola, Kujala, Laaksonen, & Aaltonen, 2013; Hannevik, Lone, Bjørklund, Bjørkli, & Hoff, 2013; Zwikael, Pathak, Singh, & Ahmed, 2013), there is potential limitation to generalisability of the findings. The research setting of upstream oil and gas provides the necessary backdrop to investigate how PBFs produce novel product innovations. It provides the necessary CoPS-like industrial setting, specifically, that inter-organisational projects are regularly conducted to produce complex engineered systems. The research was predicated on the assumption that product innovation would require firms to reach beyond their boundaries, largely because firms regularly work together in the conduct of the industry projects, and hence novel innovations would entail significant levels of inter-organisational coordination. Indeed, the findings reveal a very interdependent and open innovation process. However, generalising these findings to other settings should be done with caution. More specific limitations are discussed next.

Study 1 revealed capabilities supporting novel product innovation, including adaptive problem solving and subsequent networking capabilities. It appears that adaptive problem solving needs network connections in order to bring novel product innovations to fruition. These findings would seem to track well with the notions of innovation in complex engineering settings discussed in the project literature. Uncertainty abounds in CoPS settings, particularly oil and gas, where environmental and technological uncertainties cause situations that require problem solving to resolved (Stinchcombe & Heimer, 1985). But bringing a novel product innovation to bear on these problems appears to require involvement of network partners that is theoretically argued to be necessary in CoPS-like project networks (Gann & Salter, 2000), and shown empirically in construction industry projects (Manley, 2008) and oil and gas as well (Barlow, 2000). The limitation with these findings, in terms of the generalisability to other research settings, is tied to the level and types of uncertainty that project-based firms face, and thus the types and frequency of problems needing solved. These attributes are dependent upon the projects that typify any particular project-based industry and, moreover, the projects that particular firms choose to conduct. Upstream oil and gas has particularly unique uncertainties regarding geology, for instance (Leiponen & Helfat, 2010), that may require particular problem-solving skills not applicable to many other CoPS settings.

In Study 2, open innovation reveals that outbound non-pecuniary revealing helps to explain novel product innovation. This finding is explained in part by the strong intellectual property (IP) rights regime and the highly interdependent nature of project work that exist in CoPS industries in general, and oil and gas specifically. These strong IP rights give firms the assurances they need to share information without much concern of it being stolen or use in appropriately. However, the same attributes (strong IP regime and interdependencies) exist in the building construction industry, and there is reason to believe that outbound knowledge flows like revealing might be considerably less prevalent. Construction has relatively low investment in R&D (Reichstein, Salter, & Gann, 2008), and is typified by project owners with severe risk aversion that suppresses novel innovation activity (Keegan and Turner, 2002). These attributes would not necessarily translate into the healthy market for patented technologies and knowledge seen in oil and gas. So despite the similarities between oil and gas and construction in terms of the networked nature of production and innovation, firms in these industries might have very different open innovation profiles. In the construction industry, revealing or selling might be subservient to inbound forms of open innovation, simply because the environment is not rich with information from outbound activities (see earlier discussion on that point in 8.1). More study is needed to ascertain if this is the case.

There are a number of limitations related to Study 3. First, the applicability of the embeddedness construct to other settings may be limited. This study was predicated on the stability of the relational networks that is assumed to exist in CoPS and similar project networks. Although this stability allows one to assert that formal collaborative relationships are a valid proxy for structural embeddedness, it may not be as stable for all other project settings. For instance, network patterns may shift more quickly in industries where project durations are shorter and teams, rather than firms, are the norm, such as in film and other creative industries. Although it would be very difficult task, the direct measurement of very large industrial networks perhaps this is necessary to fully understand the power of embeddedness on innovation outcomes. Future research should look at ways to cost effectively gather structural embeddedness data on large networks.

Also in Study 3 it was found that suppliers support novel product innovation, and that customers adversely moderate this impact. On one hand, this point reflects the propensity for project owners in CoPS settings (particularly in the construction industry) to be risk-averse and to focus on tried-and-true technologies (Keegan & Turner, 2002). On the other hand, reliance on suppliers reflects global trends in oil and gas. With the exception of some of the well-recognised oil and gas majors—like Shell in particular, which conducts a significant amount of R&D—much of the investment in new technology tends to occur the lower parts of the supply chain (Perrons & Donnelly, 2012). Since the late 1970s, service firms have increasingly become the locus of technology development, as many operators have minimised their internal R&D and technology capabilities. Thus, operators are mainly considered technology adopters at this point (Bower, Crabtree, & Keogh, 1997; Crabtree, Bower, & Keogh, 1997; Daneshy & Donnelly, 2004; Grant & Cibin, 1996). An indication of this is the finding of Perrons and Donnelly (2012) that service firms produce a majority of the patent activity in their global survey of the upstream industry. Eighty per cent of the total patents reported were by service firms, and they represented only about 20 per cent of the sample. Perrons and Donnelly (2012) reveal that service firms exhibit competitive posturing with regard to intellectual property, using patents to capture market white space. Technologies actually deployed reveal a similar pattern with service firms responsible for 63 per cent of the over 1200 technologies deployed in the past three years. Operators accounted for about 26 per cent of newly deployed technologies. Hence, suppliers are definitely important in oil and gas, and thus embeddedness with them, at some level, would seem necessary to some extent.

The reliance of the supply chain to provide innovation is a potentially important point of contrast from other CoPs industries hub-and-spoke network of firms characterise the firms that coalesce around stable system integrator firms. In contrast, oil and gas may have a more segmented and specialised supply chain where end customers are less ‘co-creators’ than they are ‘buyers’ of technology. More work is necessary to directly observe the patterns of relationship to fully understand this phenomenon.

8.4.2. Internal validity

There are limitations in the research design and methods—particularly the operationalisation of variables and design of models—that the reader should consider in the context of the research findings. All three of the research studies have very parsimonious models that do not exhaustively test moderation, mediation, and interaction effects. For instance, this precluded the ability of the models to handle coupled open innovation processes—the interaction between various knowledge flows (Gassmann & Enkel, 2004). Model parsimony is driven by small sample size that limits how many variables can be tested in a single logistic model, and the models contained herein are built parsimoniously to maintain stability in the logistic regression models. Whereas the rule of thumb for ordinary least squares (OLS) regression is that there should be 10 cases for every variable included in the model, logistic regression is stricter by requiring 10 cases per the outcome category of interest. For instance, an OLS with 100 cases could accommodate 10 variables. In logistic regression, if only 30 of the 100 cases exhibit the outcome category of interest (e.g. having introduced a novel product innovation) then the model should only have around three variables to ensure stability of the model (Collett, 2003). To err on the side of caution regarding logistic model stability, the models herein do not test multiple interaction and moderation effects because of the potential for erroneous logistic regression results.

In Study 1, the capability constructs *adaptive problem solving* and *networking* are built from a series of questions about competitive advantage. Although they are theoretically justified as being salient to PBFs, and established with rigor via confirmatory factor analysis, these two capabilities do not represent complete set of capabilities that PBFs might maintain that could enhance their ability to introduce novel product innovations. The models that test the relationships between these capabilities and novel product innovations, and the moderating effect that adaptive problem solving operates through networking capability, are predicated on the absence of these other complicating factors. The models do not, for instance, test the mediating or moderating effect of R&D capability. Although the models do include a covariate indicator of R&D activity, this is insufficient to establish potentially critical role internal R&D capabilities regarding the ability to problem solve, or fully leverage network connections, toward novel product innovation ends.

Another issue with Study 1 is causality. The finding that adaptive problem solving capabilities are mediated by networking capabilities is based cross-sectional data recorded at one point in time. Thus no strong assertions about causality can be made, no matter how compelling the theory is behind it. A longitudinal study of this suspected relationship is necessary.

Study 2 also has several limitations with regard to operationalisation of variables and the models. For instance, sourcing (inbound, non-pecuniary open innovation) was operationalised using an increasingly common construct called *search breadth* (Laursen & Salter, 2006). Search breadth has become central to the open innovation literature, much of it showing that broad search has a positive relationship to innovation (e.g., Leiponen and Helfat, 2010), and perhaps a curvilinear effect (inverted-U) at high levels of search breadth (Laursen & Salter, 2006). However, the current research reveals the opposite relationship: broad search has a direct negative relationship. Similarly this means that narrow search is positively related to novel product innovation in this setting. Although several plausible and theoretically justifiable explanations were employed to explain this counterintuitive result in the study chapter, this thesis cannot test these alternatives. The fact remains that search breadth may not adequately explain inbound non-pecuniary flows that occur in highly networked environments. Firms in such settings may be subject to higher levels of knowledge spillovers, simply from the inter-organisational projects they conduct. The same goes for outbound non-pecuniary *revealing* which, in the current study, is operationalised by two variables indicating these knowledge flows. Although the findings regarding reveals make theoretical sense—particularly that *revealing* activities precede R&D activities, and this is done to ensure that novel product innovations fit the needs of the network partners—there are likely many other outbound non-pecuniary flows that were not directly measured. Thus Study 2 suffers because there are likely aspects of open innovation might be present but were not measured, and these may be the true pathways by which non-pecuniary information enters (and exits) the firm to support novel innovation activities. Compounding this problem are the tests for moderation. Consequently, much more work is required to develop the metrics that might more accurately measure the multidimensional construct of open innovation and to test more thoroughly the relationship between these aspects and outcomes like novel product innovations.

The use of the moderating variable R&D is a limitation in Study 2. Operationalised as the presence of R&D, it may be an insufficient delineator of the absorptive capacity differences of firms. Absorptive capacity plays an important role in the firm's ability to transfer and consume innovation information across its boundaries (Cohen & Levinthal, 1990). The underlying survey data were not able to support more sophisticated operationalisations such as R&D intensity, derived from the percent of revenues devoted to R&D activities. Study 2 also cannot make claims about causality, because the data are cross-sectional in nature. The theoretical argument that to explain how revealing operates through firms' R&D activities in order to support novel product innovation needs to be tested in a more sequential manner to understand exactly how this occurs.

Also regarding Study 2, the lack of longitudinal data and better R&D intensity measures may explain the lack of support for the hypothesis that R&D mediates the relationship between sourcing (search breadth) and novel product innovation. The search for innovation information would likely pre-date eventuality of a novel product, and the lack of longitudinal data may have obscured this fact. Further, lack of a detailed R&D intensity measure does not provide insight into the relative absorptive capacity levels that would that underpin firms' ability to make use inbound knowledge flows. Thus it is not possible to say definitively that broad search is unimportant to novel product innovations in this setting, and more research is necessary.

Study 2 is also limited as it does not look at the underlying motivations that may underpin a firm's decisions to engage in specific open innovation activities. Although these are outside of the scope of the current thesis, they nonetheless require investigation. If these motivations were more clearly related to the broader-based set of open measures called for above, this would provide great insight into the phenomena of open innovation in PBFs. At current this is a major limitation of the research.

Study 3 too has several limitations. Embeddedness was measured in a cross-sectional manner when it is argued to be a dynamic process that evolves over time (Manning & Sydow, 2011). Observing these shifts might require a qualitative, process-oriented method. If quantitative methods are used, then longitudinal analysis is necessary. The proxy measure developed herein could be used in a longitudinal fashion, providing snapshots of the dynamic changes of inter-organisational relationships. Longitudinal studies can uncover the shifts regarding embeddedness on the eventuality of novel product innovations.

In terms of the specific findings of Study 3, there is some ambiguity over the specific inflection point where supplier over-embeddedness begins to detract from novel product innovation. The inflection point where the probability of novel product innovation begins to decrease, with regard to supplier embeddedness, is shown to be around three or four. These numbers are just an artefact of the operationalisation of embeddedness, which is simply the total out of nine formal collaboration modes that could potentially occur with customers and suppliers. The nine formal collaboration modes do not represent an exhaustive list by any measure. Thus, the findings are simply indicative and require more study.

8.5. Future research

Based on the findings of this thesis, a conceptual diagram was created to map the various constructs and highlight areas for future research (Figure 19). Mapped in solid black lines are the statistically significant relationships. For instance, the findings of Study 1 are shown as 'problem solving' leading to 'networking' and on to 'novel product innovations'. From Study 2, 'revealing' and 'narrow search' leads to novel products, and 'broad search' leads to incremental innovation (a speculation that found some empirical support in post-hoc tests—see Chapter 5). Finally, from Study 3, 'supplier embeddedness' is shown to relate to 'novel product innovation'.

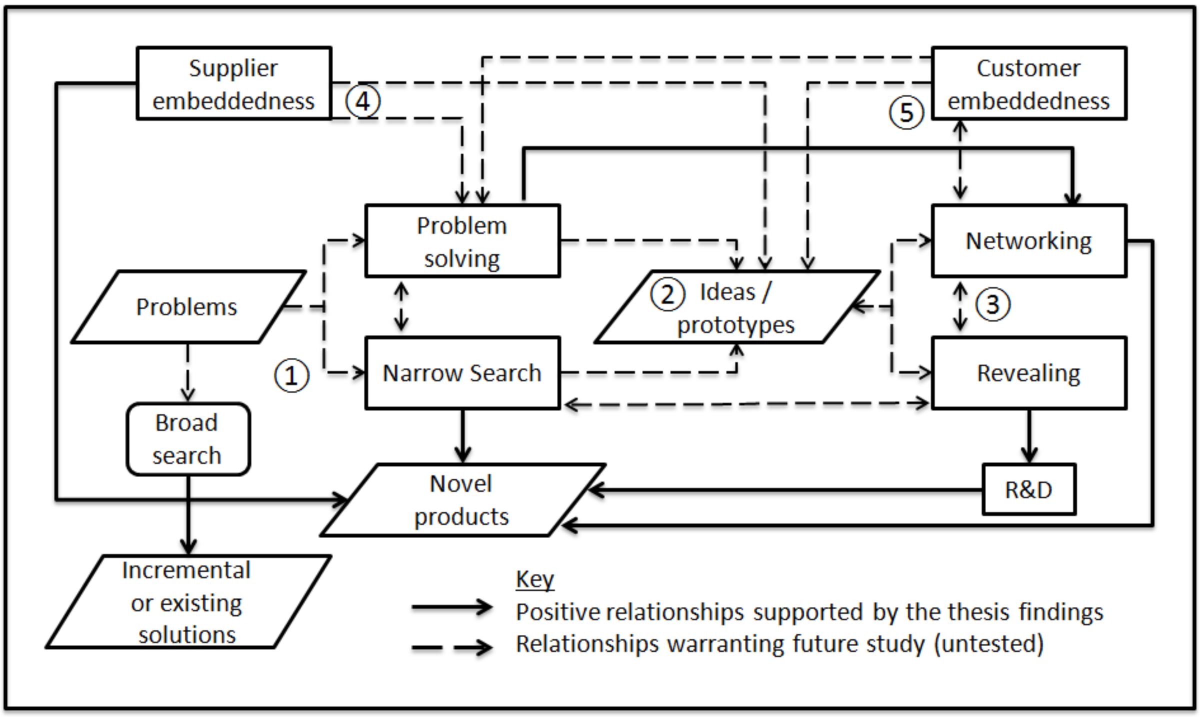

Figure 19 - Areas for future research

Areas for future research surround these themes and are noted by number on the figure. At the left of the diagram is 'problems', which is a stand-in for the industry circumstances that present themselves in the context of project requirements or technology shifts affecting firms in the project-based productive network. The presumption is that problems vary in their specific nature and magnitude, but that they are specifically related to collective industry challenges. Related to these challenges is the ability of the firm to engage in problem solving (adaptive problem-solving capabilities, Study 1). We also know that search is a problem-solving-related activity, and in particular, that narrow patterns relate to novel products, and perhaps that broad search may relate to incremental innovations (Study 2). The issue for future researchers would be to improve our understanding relative to the different problem sets that drive different search patterns (Location 1 on the diagram). Under which circumstances is broad search instigated, and is it really related to incremental innovations? Are there different aspects of adaptive problem-solving capability that have not been established in this thesis that might make firms prone to one type of search versus the other?

There are several findings that imply that technologies are shared in incomplete forms. To capture this Location 2 on the diagram is parallelogram representing 'ideas/prototypes' is listed as an intermediate output. Study 2, for instance, finds that revealing of innovation details solicits information from network partners that is subsequently used to refine the innovation before it is introduced. This implies that the novel product innovation (in some form or another) has been shared. Thus, the question posed that cannot be answered here, is what are the relationships between the precursors of the prototype (problem solving and narrow search), and the subsequent steps (networking and revealing—and subsequently, additional R&D for the latter)? How iterative is this process? Location 3 also speaks to this issue, specifically relating to the relationship between networking capabilities and revealing activities. These are arguably closely related activities, since revealing likely involves networking partners. But is revealing perhaps part of a standard networking capability as well? Is networking capability, particularly the technological breadth component, form some externally housed absorptive capacity that allows the feedback to be absorbed into the focal firm? Network partners have indeed been argued to help ascertain the value of information for the purposes of innovation (Ahuja, 2000).

Finally, Locations 4 and 5 relate to delineating more specific effects of supplier and customer embeddedness at different stages of innovation development (Knudsen, 2007). The questions posed for each are the same. How does customer and supplier structural embeddedness impact problem solving and ideation/prototyping stages? Are there differences depending on the stage of development? Will customers be more prone to accept and support well-developed innovations and unlikely to support more basic problem solving activities? Does this have follow-on effects; for instance does customer embeddedness affect problem solving such that it also affects the firms' search patterns? Can customers' desires for reliable solutions drive PBFs to search far and wide for existing solutions rather than developing a new solution? Could this chain of events drive broad search, yielding incremental solutions? In terms of supplier embeddedness, at what point are suppliers more beneficial—problem solving, or prototyping? Of course there are multiple theoretical lenses that could be applied to the study of this phenomenon of supplier and customer influence on novelty and the role of contracts as both potential inducements and barriers to innovation should be explored (Williamson, 2008).

Another area worth investigating is the relationship between embeddedness and networking capabilities in order to understand how the latter might help overcome the deleterious effect of the former. Are firms that have many deep relationships able to fend off the potential push toward incremental innovations with high levels of networking capabilities? It may be that a firm's ability to manage the relationship tensions, perhaps by engendering creative conflict, may help to support more novel innovation outcomes. There is a need to understand how these things interact which is beyond the scope of the current study.

This diagram is of course only notional, but highlights the fact that, while this thesis contains many useful insights, many questions still remain that need to be investigated. The world of PBFs—and their position in project-based productive networks—should continue to be studied, since there are many outstanding questions needing answers, and many new insights yet to be gained.

8.6. Closing thoughts

This thesis provides some new insights into how project-based firms introduce novel product innovations in environments where inter-dependent firms contribute to system-level technological outcomes. In many ways, it challenges orthodox thinking on innovation as an individual firm pursuit, and re-characterises the innovation process—for PBFs operating in CoPS settings at least—as a collective pursuit of improved technology to support industry objectives. Capabilities relating to problem-solving activities that arise due to the conduct of industry projects are coupled with network connections to explain how novel products come about. Non-pecuniary knowledge flows, particularly outbound revealing, show that firms have to integrate internal R&D with external feedback from network partners to introduce novel products. Ties with suppliers are important, but not too many, lest they begin to limit the ability to manoeuvre into novel spaces, as might customer involvement. Overall, these results reveal the notion that PBFs must simultaneously integrate with the network but maintain some flexibility to innovate in novel ways. This is the tension that PBFs must manage. The mechanisms investigated herein provide some insight into how this tension is managed, but there remains much to study.

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APPENDICIES

9.1. Ethics

The following email trail document reveals that existing ethics approval covers the research contained in this thesis (also see section 3.2.3).

RE: Ethics Application-Jerad FORD-27/8/2012

Ravi Pappu
Sent: Monday, 27 August 2012 4:42 PM
To: Jerad Ford
Cc: Vivienne Balson; Martie-Louise Verreynne; John Steen

Dear Jared

I can confirm that ethics approval is not required for the study discussed in this email.

All the best
Ravi

-----Original Message-----
From: Jerad Ford
Sent: Monday, 27 August 2012 4:35 PM
To: Ravi Pappu
Cc: Vivienne Balson; Martie-Louise Verreynne; John Steen
Subject: RE: Ethics Application-Jerad FORD-27/8/2012

Ravi,

Thanks for the email. I think it would be extremely difficult or nearly impossible for firms to be singled from the data I would be using. That being said, Martie-Loiuse does have approval under her ethics approval share with me the names of the firms participating in the survey but with no information attached. The information itself is de-identified. Understanding which firms participated might be important. It would let me to know whether firms which are central to the industry are part of the sample set or not, and aid in the interpretation of data.

Based on this, I'll leave it up to you whether it needs to go through formal ethics approval. I didn't think it was necessary in the first place, but heeded your advice to submit this partial application to be safe.

Thanks,
Jerad

From: Ravi Pappu
Sent: Monday, 27 August 2012 2:42 PM
To: Jerad Ford
Cc: Vivienne Balson; Martie-Louise Verreynne; John Steen
Subject: Ethics Application-Jerad FORD-27/8/2012

Dear Jerad

I received read your application for ethics approval using secondary data from Dr Martie-Louise.

I have carefully read the application.

If, from the publication and sharing of the results of your research- the participants can not be identified (even though there is no identification information) either by their employers or by competitors (e.g. firms in the industry)-then, you will not need ethics approval separately. Let me know if this is not the case-I will arrange a review of the application.

Your research involving analysis of secondary data would be covered by the approval earlier obtained by Martie-Louise.

Regards
Ravi

Ravi Pappu
PhD (UNE), MBA, PGDipMktg (Waikato), B.Tech. Mech Engg. (JNTU)

Chair, UQBS Ethics Committee
Seminar Series Coordinator for the Marketing Cluster UQ Business School

Faculty of Business, Economics and Law
The University of Queensland
Brisbane, QLD, 4072 Australia
Office: 416, Colin Clark building (39)
Phone: +61 7 3346 8089
Email: r.pappu@business.uq.edu.au

Web: http://www.business.uq.edu.au/display/teach/Ravi+Pappu
Web: http://www.uq.edu.au/uqresearchers/researcher/pappurs.html

9.2. Questionnaires

The following sub sections contain the questions that were administered by phone in each year. Please note that the data contained in each case were transformed into computer-assisted telephone interviewing (CATI) system. Thus no special formatting of the instruments was attempted since they were not viewed in hard copy by respondents.

9.2.1. Survey questions from 2012

SECTION A GENERAL CHARACTERISTICS OF YOUR BUSINESS

IN THIS SECTION WE WOULD LIKE YOU TO DESCRIBE THE KEY CHARACTERISTICS OF YOUR BUSINESS.

A1. In what year did your Australian organisation start operating?

A2. Which structure below best describes your organisation?
(Please tick one or more boxes)

- Part of a group of companies?
- International organisation subsidiary?
- Independent business unit?.
- A Joint Venture?
- A sole ownership?
- A partnership?
- A company?
- Family Business?
- Franchisor?
- Franchisee?

A3. Please answer each of these questions about yourself

What is your current role within your organisation?	Board member. Business Executive, Owner, General Manager, Supervisor or Other
Years in the industry?	Yrs
Years with within your current organisation?	Yrs
Years and/or months in your current role?..........................	Yrs
Age?	Yrs
Gender?..	Male Female
Highest level of education	Options: High School: University (first degree); University (second degree); Tafe certificate or diploma.

A4. Position in the Oil and Gas industry.

a. Please indicate which part(s) of the Oil and Gas value chain your company participates in.

	Do you participate in?	IF YES please indicate the % of business activity
Upstream oil and gas (exploration and production of petroleum and/or gas, gathering systems, and transportation and storage of petroleum and/or gas products)	Yes No	%
Downstream (refining / processing (including LNG processing) / retailing of petroleum/ gas products / electricity generation)	Yes No	%
Services (serving all parts of the value chain)	Yes No	%

b. Can you please provide your best estimate of your firm's revenues for 2011/2012 or the most recent reporting year

revenues for 2011/2012 (or most recently available) $

c. Can you please provide percentages of revenues as derived from:

(note to interviewer: would be read as "percentages of revenues as derived from conventional oil…. Conventional gas?, Unconventional oil…… unconventional gas? And finally renewable energy") Capture the total of conventional and unconventional in the third column if respondent cannot split between oil and gas.

	Oil	Gas	Renewable	Total (if can't split)
Conventional	%	%		%

	Oil	Gas	Renewable	Total
Unconventional (for example, coal seam gas)	%	%		%
Renewable energy (non carbon eg Solar, Wind)			%	

d Can you please provide your best estimate of **Capital Expenditures** for for 2012/2012 (or most current reporting year)

Capital expenditures for 2012/2012 | $

e. Can you please allocate percentages of capital expenditures toward….:

*(**note to interviewer**: would be read as "percentages of capital expenditures toward conventional oil….Conventional gas?, Unconventional oil…… unconventional gas? And finally renewable energy") Capture the total of conventional and unconventional in the third column if respondent cannot split between oil and gas.*

	Oil	Gas	Renewable	Total (if can't split)
Conventional ………………………………………	%	%		%
Unconventional (for example, coal seam gas)	%	%		%
Renewable energy (non carbon eg Solar, Wind)			%	

A5. Provide the best estimate of your workforce **excluding construction workers** that are currently employed in the occupation groups listed below? *(Please enter number of full/part time employees* **and** *indicate if you provide formal training for* **each** *type of employee)*

NOTE to interviewer: Accurate and representative approximations of numbers are satisfactory if exact numbers are not possible.

	No. of employees as of **June 1, 2012**			Do you Provide formal Training?	
	Total	Full Time	Part Time		
Managerial……………………………………………				Yes	No
Technologists, scientists, engineers & higher professionals ………………………………………………………				Yes	No
Functional experts (e.g finance, HR, procurement, project management, risk management)………………………………				Yes	No
All other employees…………………………………				Yes	No
Total non-construction workforce					

A6. Please provide your best estimate of the number of construction workers and other contract staff relative to Capital Expenditures (CAPEX) related activities and Operations and Maintenance (O&M) Activities.

	CAPEX	O&M
No. of staff		

A7. Does your firm explicitly track and monitor production efficiency performance? (***note to interviewer*** applicable mostly to oil and gas production entities, or perhaps other manufacturing entities) — Yes No

A8. Does your firm explicitly monitor track labour productivity performance? — Yes No

If the answer is 'No', please go to Section B

A9. Does your labour productivity metric have a material weighting factor or other measure to compensate for capital intensity? — Yes No

A10. Can you describe a little more about ways how you measure productivity performance at your organisational level?

………

A11. Has productivity performance increased, decreased or stayed the same in your organisation since last year?

Increase [ ]
Decrease [ ]
No change [ ]

SECTION B COMPETITIVE SITUATION AND COLLABORATIVE ACTIVITY

IN THIS SECTION WE WOULD LIKE YOU TO GET A BETTER UNDERSTANDING OF YOUR COMPETITIVE SITUATION AND LEVEL OF COLLABORATION AND PARTNERSHIP

B1. Based on the list below, how would you rate your competitive advantages on a scale of 1 to 5? *Please circle the appropriate number in* **each** *row.*

Note to SSI: include N/A as a blind option

	Not a competitive advantage	A slight competitive advantage	A competitive advantage	Significant competitive advantage	Key differentiator
Established reputation	1	2	3	4	5
Marketing and promotion skills	1	2	3	4	5
Cost advantages	1	2	3	4	5
Specialised expertise/product/service/technology........	1	2	3	4	5
Range of expertise/products/services/technology........	1	2	3	4	5
Supply chain management and integration........	1	2	3	4	5
Ability to execute on projects in a timely manner........	1	2	3	4	5
Mega infrastructure project management expertise........	1	2	3	4	5
Partner network & related arrangements	1	2	3	4	5
Health, Safety, Security and Environmental record	1	2	3	4	5
Stakeholder management *(e.g. soliciting and actively managing feedback, across project life cycle)*........	1	2	3	4	5
Other (please specify and rank)........	1	2	3	4	5

B2. Which of the following best describes the growth objectives of <u>your Australian organisation</u> for the next 3 years? *Please tick* **one** *box.*

Stay same size ☐ Grow moderately ☐ Grow substantially ☐

(Note **to interviewer ....Zero growth rate ... .Single digit growth rate ....Double digit growth rate)**

B3. In the last 3 years has your firm purchased another business or portion of another business? Yes No

B4. What percentages of products/services from your Australian organisation are targeted at the following markets?

	Current Year
Local area (area, city of town where business is located)	%
Other Australia........	%
New Zealand........	%
Asia........	%
North America (including Mexico)........	%
Europe	%
Other international (Please Specify)........	%
Total	100%

B5. We consider collaborations those that are beyond the normal day to day operations of the firm that strive for improving some aspect of the business. Has your organisation engaged to-date in formal or informal collaborative/ partnership arrangements with any other organisations Yes No

IF NO, PLEASE GO TO B8

IF YES,

B6. Please indicate which type of collaboration/partnership **excluding equity joint ventures** you are/were engaged in and with whom?
Circle the appropriate answers in **each** *row.*

	Engaged in arrangement		Suppliers	Customers	Higher Education/ Research Institutes	Private Research Institutes/ Consultants	Firms in your line of business
1. Management and staff development	Yes	No	1	2	3	4	5
2. Gaining access to (or spread costs) of new equipment, technology or information sources	Yes	No	1	2	3	4	5
3. Purchasing jointly materials or inputs	Yes	No	1	2	3	4	5
4. Streamlining the supply chain	Yes	No	1	2	3	4	5
5. Outsourcing aspects of your business operations	Yes	No	1	2	3	4	5
6. Improving and sharing infrastructure (roads/pipes/rails)	Yes	No	1	2	3	4	5
7. Development of specialist services /products required by customers?..........................	Yes	No	1	2	3	4	5
8. Sharing research and/or development activity	Yes	No	1	2	3	4	5
9. Involvement in collaborative R&D activities funded through grants	Yes	No	1	2	3	4	5
10. Other? Please specify	Yes	No	1	2	3	4	5

B7. What would you describe as your top 3 critical success factors to productive collaboration/partnerships?

....

Note to SSI – code into three boxes, and include prioritization

....

B8. Relative to contracting methods of your firm.

A. Do you engage in any performance-based contracts with incentives? Yes No

B. if yes, approximately what percentage of your firm's contracts are performance-based? %

C. Would your firm prefer to engage in more performance-based contracting? Yes no

B9. Given your firm's history in the last 3 years, which of the following factors have acted as a significant limitation or barrier on your ability to meet your business objectives? *Please circle the appropriate number in* **each** *row.*

	Insignificant limitation	Slightly significant limitation	Moderately significant limitation	Very significant limitation	Crucial limitation
Inequitable risk sharing in contractual relationships........	1	2	3	4	5
Ability to meet incentive targets on contracts	1	2	3	4	5
Availability and cost of finance for expansion......................	1	2	3	4	5
High cost of doing business in Australia (strong A$)	1	2	3	4	5
Labour productivity..	1	2	3	4	5
Skilled labour..	1	2	3	4	5
Management skills	1	2	3	4	5
Marketing and sales skills	1	2	3	4	5
Acquisition of technology	1	2	3	4	5
Difficulties in implementing new technology......................	1	2	3	4	5
Access to overseas markets	1	2	3	4	5
Increasing competition	1	2	3	4	5
Government regulations and compliance (red-tape)...........	1	2	3	4	5
Lengthy project approval processes........................	1	2	3	4	5
Environmental compliance (green-tape)...........................	1	2	3	4	5
Environmental regulatory uncertainty............................	1	2	3	4	5
Current infrastructure bottlenecks..................................	1	2	3	4	5

Future infrastructure availability uncertainty (e.g. plans for ports, rails, etc)………	1	2	3	4	5
Social licence to operate (e.g. Land access issues, community relations) ………………………………………………	1	2	3	4	5
Other (Please specify)…………………………………………………	1	2	3	4	5

B10. What are the global and/or local challenges that have the biggest impact on your business?

……

……

SECTION C INNOVATION

IN THIS SECTION WE WOULD LIKE YOU TO TELL US ABOUT YOUR INNOVATIVE ACTIVITY.

- *Please count innovation as occurring when a new or significantly improved manufactured product, or service product, is introduced to the market ("product innovation"), or when a new or significantly improved production, or delivery method, is used commercially ("process innovation"), and when **changes** in knowledge or skills, routines, competence, equipment, or engineering practices are **required** to develop or make the new product, or to introduce the new process.*
- *Please do **not** count as product innovation, changes which are purely aesthetic (such as changes in colour or decoration), or which simply involve product differentiation (that is minor design or presentation changes which differentiate the product while leaving it technically unchanged in construction or performance). The implementation of a quality standard is not innovation unless it is directly related to the introduction of technologically new, or significantly improved, products or processes*

C1. Has your firm introduced any of the following technology, service, or managerial innovations **in the past 3 years?**
(***note*** if multiple examples of each type, capture all information on same line)

	(If no skip to next row)		If YES, *was the innovation…* …new to your firm **AND** to your Industry?		…new to your firm but **NOT** to your Industry?	
Technologically new or significantly improved physical product / technology………	Yes	No	Yes	No	Yes	No
Technologically new or significantly improved **methods of producing** a physical product / technology	Yes	No	Yes	No	Yes	No
Technological improvements in supply, storage or distribution systems for physical product / technology……………	Yes	No	Yes	No	Yes	No
New or significantly improved 'service product'………………………………………	Yes	No	Yes	No	Yes	No
New method to produce and deliver your 'service product'………………………	Yes	No	Yes	No	Yes	No
New organisational/managerial processes or marketing methods………………………………	Yes	No	Yes	No	Yes	No

↓

IF YOU CIRCLED NO IN ALL BOXES PLEASE GO TO <u>C7</u>

C2. If Yes, please describe in a few words your innovation and the value generated/anticipated?

……

C3. Please attribute your Australian organization's business total activities as derived from the following 3 types of innovation? ***(note to interviewer: should not add up to more than 100%)***

Products/technologies or services **unchanged or only marginally changed** in the last 3 years	%
Significantly improved products/technologies or services introduced within the last 3 years……………	%
New products or services introduced within the last 3 years…………………………………………………	%

C4. How were your innovations developed in the last 3 years?

Mainly within your firm or firm group		Mainly in collaboration with other firms or institutions		Mainly adopted after development by other firms or institutions		Adopted from parent firms (in the case of JVs)	

C5. Has your organisation been involved in one or more of the following activities, in the last 3 years?

- Filed for patents, trademarks or service marks ☐
- Licensed patents or technical information directly to another party for a fee, or royalty payments, or other type of compensation? *(this includes any arms-length relationships like JVs or subsidiaries)* ☐
- Shared technical details openly to the industry to spur subsequent innovation or adoption of technology *(e.g. any way real technical detail is shared externally but with no immediate direct monetary benefit)* ☐
- Shared technical information via confidentiality agreements in order to explore potential larger partnerships or licensing opportunities ☐

C6. Please indicate the importance of the following internal sources (these include management, production, research & development (R&D), sales and marketing functions) and/or external sources of information for your firm's innovation activities during the last 3 years. *Please circle the appropriate number in* **each** *row.*

	Not a source	An insignificant source	A common source	Very significant source	Crucial source
Internal Sources:					
within the firm	1	2	3	4	5
within the group (if you have subsidiary or associated firms, or from JV parents)............	1	2	3	4	5
External Sources:					
suppliers of equipment, materials and components	1	2	3	4	5
clients or customers	1	2	3	4	5
competitors in your line of business	1	2	3	4	5
consultancy firms............	1	2	3	4	5
financiers (e.g. venture capitalists)	1	2	3	4	5
universities/higher education institutes	1	2	3	4	5
government or private non-profit research institutes	1	2	3	4	5
patent disclosures	1	2	3	4	5
professional conferences, meetings, professional journals............	1	2	3	4	5
fairs/exhibitions	1	2	3	4	5
trade associations, chambers of commerce	1	2	3	4	5
computer-based information networks............	1	2	3	4	5

C7. Did your firm engage in research and development (R&D) in the last financial year?............ Yes No

IF NO, PLEASE GO TO SECTION D,

IF YES: How many staff were engaged in research and development (R&D)?

for part of their time .... ☐ for all of their time .... ☐

What was your total annual R&D expenditure?............ $

SECTION D FINANCE

D1. Have you made attempts to obtain additional finance in the last 2 financial years for your Australian organisation? | Yes | No |

IF NO, PLEASE G to Section E

IF YES, roughly what amount did you seek and what proportion of the overall amount you sought did you obtain? *If you were completely unsuccessful in obtaining finance enter* **NIL** *in the percentage obtained box.*

Amount sought........................ $ 000 Percentage obtained .... %

SECTION E YOUR AUSTRALIAN ORGANISATION PERFORMANCE

IN THIS SECTION WE WOULD LIKE TO CONCLUDE BY GATHERING SOME ADDITIONAL INFORMATION ON YOUR AUSTRALIAN ORGANISATION **ONLY**

E1. Please provide the following information on the scale of your business for the latest financial year for which you have data available. *Please specify the accounting month and year end and the number of months covered in that year.*

Accounting year ending: .... Month Year No. of months covered

Pre-Tax profits (losses) including directors', partners' or owners' remuneration, but before deduction of interest and tax .... A$

Total annual wage and salary bill excluding directors', partners' or owners' remuneration . A$

E2. To help us understand how your business has evolved, please provide the equivalent information **for 3 years ago**. Please specify the accounting month and year and the number of months covered in that year.

Accounting year ending: .... Month Year No. of months covered

Turnover .... A$

Exports.. A$

Pre-Tax profits (losses) including directors', partners' or owners' remuneration, but before deduction of interest and tax .... A$

Total annual wage and salary bill excluding directors', partners' or owners' remuneration . A$

Capital expenditures .... A$

Average number of full time employees (including working directors) ....

Average number of part time employees (**optional**) ....

Average hours worked by part time employees per week (**optional**).................................

E3. We would like to interview select participants at later date, as well as to conduct case studies. Some exemplary examples of innovation success stories will be included in the final report.

If contacted, would you be willing to take part in a subsequent interview? .... Yes No

E4. **IF YES** Are there other senior members of the company we also should talk to? (LIST) Yes No

(Names, Phones, Emails)...

....

WE SINCERELY APPRECIATE YOUR TAKING THE TIME TO ANSWER THESE QUESTIONS.

IF YOU HAVE ANY QUESTIONS PLEASE PHONE: +61 7 3346 8160, OR EMAIL: m.verreynne@business.uq.edu.au

APPROVED BY THE UNIVERSITY OF QUEENSLAND BEHAVIOURAL & SOCIAL SCIENCES ETHICAL REVIEW COMMITTEE, on 6th November 2009 for a period of five years, Reference Number 2009001621.

9.2.2. Survey questions from 2013 / 14

Note: Question numbering an artifact of the system generated format, please disregard. Questions appear in the order they appear below.

Q1 In what year did your Australian organisation start operating?

Q9 Which structure below best describes your organisation? (Please tick one or more boxes)

Part of a group of companies (1)

Subsidiary of an international organisation (2)

Independent business unit (3)

Joint venture (4)

Independent company (5)

Q2 What is your current role within your organisation?

Board member (1)

Executive (2)

Owner (3)

General Manager (4)

Supervisor (5)

Other (please name) (6) ____________________

Q3 Years in the industry?

Q4 Years within your current organisation?

Q5 Please indicate the Oil and Gas value chain position that BEST characterises the activities of your firm

Oil and gas Operator (upstream exploration and production or downstream refining and processing and sales) (1)

Contractor (e.g. oil field services, engineering, construction, logistics, maintenance (NOT suppliers of special material/equipment/services) (2)

Suppliers of material, equipment and services (basic materials, specialised products and services (e.g. 3D seismic)) (4)

If oil and gas operator then

Q6 Please enter the percent of your TOTAL business activity associated with these OPERATOR types

1) ______ Upstream (exploration and production of petroleum and/or gas, gathering systems, and transportation and storage of petroleum and/or gas products) (1)

2) ______ Downstream (refining / processing (including LNG processing) / retailing of petroleum/ gas products / electricity generation) (2)

If contractor then

Q7 Please enter the percent of your TOTAL business activity associated with these CONTRACTOR types

3) ______ Oil field services including drilling and completions, workovers, etc. (1)

4) ______ Engineering (2)

5) ______ Construction (3)

6) ______ Engineering Procurement and Construction (EPC) (4)

7) ______ Logistics (5)

8) ______ Maintenance (6)

9) ______ Other (7)

If supplier then

Q8 Please enter the percent of your TOTAL business activity associated with these SUPPLIER types

10) ______ Basic material suppliers (1)

11) ______ Equipment and specialised equipment (2)

12) ______ Specialised services like 3-D seismic (3)

13) ______ Other (name) (4)

Q47 Are you participating in any part of a megaproject (where the total value exceeds $1billion, like GORGON, APLNG, GLNG, QCNLG, INPEX, etc.)

Yes (4)

Maybe (5)

No (6)

Q10 Please tell us about projects conducted with other firms (slide the indicator)

14) ______ Percentage of total business volume that is conducted through projects (1)

If projects is more than zero then

Q12 About your projects

15) ______ Average number of projects per year your firm conducts (1)

______ Typical project size ($AUD) (2) Basis: Revenue [ ] or Cost [ ]

[ ] Less than $1m

[ ] $1m to $9m

[ ] $10m to $99m

[ ] $100m to $999m

[ ] Over $1b

16) ______ Largest project size ($AUD) (3) Basis: Revenue [ ] or Cost [ ]

[ ] Less than $1m

[ ] $1m to $9m

[ ] $10m to $99m

[ ] $100m to $999m

[ ] Over $1b

Q.101

Provide the best estimate of your firm's workforce as full-time equivalents (FTE)

	All functional, managerial and technical positions	Construction
Internal (Non-contract) workforce		
Contract workforce		

Q48 Does your firm measure any type of productivity or efficiency (labour, production, capital or similar)?

Yes (1)

No (2)

If yes then Q17 Please provide information on productivity

	Do you Measure?		in the last year has it...			How much?		
	Yes (1)	No (2)	Decreased? (1)	Stayed same? (2)	Increased? (3)	0 to 9% (1)	10 to 24 % (2)	more than 25% (3)
Does your firm explicitly track and monitor production efficiency performance? (1)								
Does your firm explicitly monitor track labour productivity performance? (2)								
Does your firm explicitly monitor track capital productivity performance (includes if this is part of a material weighted labour productivity calculation)? (3)								
Does your firm track and monitor some other form of productivity? (list please) (4)								

Q22 Can you please allocate current Business Activity as a percent of the total, across these categories of energy business? For 2012/2013 (or the most recent reporting year)

17) ______ Conventional Oil (%) (1)

18) ______ Conventional Gas (%) (2)

19) ______ Unconventional Oil (%) (3)

20) ______ Unconventional Gas (e.g. coal seam gas) (%) (4)

21) ______ Renewable energy (e.g. Solar, Wind) (%) (5)

22) ______ Other (6)

Q23 Estimating three years **into the future**, Can you please allocate expected Business Activity as a percent of the total, across these categories of energy business?

23) ______ Conventional Oil (%) (1)

24) ______ Conventional Gas (%) (2)

25) ______ Unconventional Oil (%) (3)

26) ______ Unconventional Gas (e.g. coal seam gas) (%) (4)

27) ______ Renewable energy (e.g. Solar, Wind) (%) (5)

28) ______ Other (6)

Q24 Did your firm engage in RESEARCH AND DEVELOPMENT (R&D) in the last financial year?

Yes (1)

No (2)

If yes

Q26 What is your estimated annual R&D budget for the most recent reporting year ($AUD)

Q28 Number of R&D employees (full time equivalents)

If oil and gas operator, ask

Q25 Did your firm engage in EXPLORATION AND PRODUCTION (E&P) in the last financial year?

Yes (1)

No (2)

If yes then

Q27 What is your estimated annual E&P budget ($AUD)

Q29 Number of E&P employees (full time equivalents)

Q30 Can you provide your firm's estimated Capital expenditures ($AUD) For 2012/2013 (or the most recent reporting year)

Q31 In the last 3 years has your firm purchased another business or portion of another business?

Yes (1)

No (2)

Q32 Which of the following best describes the growth objectives of your Australian organisation for the next 3 years?

Stay the Same Size (0%) (1)

Grow Moderately (1-9%) (2)

Grow Substantially (10%+) (3)

Q33 Based on the list below, how would you rate your competitive advantages on a scale of 1 to 5?

	Not a competitive advantage (1)	A slight Competitive advantage (2)	A competitive advantage (3)	A Significant competitive advantage (4)	A Key differentiator (5)
Established reputation (1)					
Marketing and promotion skills (2)					
Cost advantages (3)					
Specialised					

expertise/product/service/technology (4)					
Range of expertise/products/services/technology (5)					
Supply chain management and integration (6)					
Ability to execute on projects in a timely manner (7)					
Rigorous project risk management (8)					
Partner network & related arrangements (9)					
Innovative problem-solving within projects (10)					
Ability to adapt to changing and unexpected circumstances in projects (11)					
Documenting and transferring lessons learned across projects (12)					
Other (please specify and rank) (13)					

Q34 Provide estimate of revenue splits (%) by Australian jurisdiction

29) ______ Queensland (QLD) (1)

30) ______ New South Wales (NSW) (2)

31) ______ Victoria (VIC) (3)

32) ______ Tasmania (TAS) (4)

33) ______ South Australia (SA) (5)

34) ______ Western Australia (WA) (6)

35) ______ Northern Territory (NT) (7)

36) ______ Australian Capital Territory (ACT) (8)

37) ______Commonwealth (9)

Q35 FORMAL COLLABORATIONS

Has your organisation engaged to-date in formal or informal collaborative/ partnership arrangements with any other organisations, that strive to improve some aspect of the business beyond the normal day to day operations?

yes (1)

No (2)

If No Is Selected, Then Skip To Q38

Q36 Please indicate which type of collaboration/partnership excluding equity joint ventures you are/were engaged in and with whom?Multiple answers are encouraged

	None (1)	Suppliers (2)	Customers (3)	Higher Education / Research Institutes (4)	Private Research Institutes/ Consultants (5)	Firms in your line of business (6)
Management and staff development (1)						
Gaining access to (or spread costs of) new equipment, technology or information sources (2)						
Purchasing jointly materials or inputs (3)						
Streamlining the supply chain (4)						
Outsourcing aspects of your business operations (5)						
Improving and sharing infrastructure (roads/pipes/rails) (6)						
Development of specialist services /products required by customers (7)						
Sharing research and/or development activity (8)						
Involvement in collaborative R&D activities funded through grants (9)						
Other? Please LIST (10)						

Q38 Please select the types of contracting methods your firm engages in, and whether that type is used with each entity. (multiple selections possible)

	None (1)	Suppliers (2)	Customers (3)	Higher Education/ Research Institutes (4)	Private Research Institutes/ Consultants (5)	Firms in your line of business (6)
Alliance or partnering (1)						
Joint Venture (2)						
Engineering, Procurement and Construction (EPC) (3)						
Term contracts of service or supply (4)						
Lump sum contracts (including milestone-based) (5)						
Cost plus fee (6)						
Performance based with incentives (7)						
Other (Please name) (8)						

Q39 Given your firm's history in the last 3 years, which of the following factors have acted as a significant limitation or barrier on your ability to meet your business objectives?

	Insignificant limitation (1)	Slightly significant limitation (2)	Moderately significant limitation (3)	Very significant limitation (4)	Crucial limitatio n (5)
Inequitable risk sharing in contractual relationships (1)					
Ability to meet incentive targets on contracts (2)					
Exceeding budget and/or schedule on projects (3)					
Scope changes in projects (4)					
Contractual disputes (5)					
High cost of doing business in Australia (strong A$) (6)					
Poor Labour productivity (7)					
Skilled labour (8)					
Management skills (9)					
Marketing and sales skills (10)					
Learning about technology (11)					
Acquisition of technology (12)					
Implementing and using new technology (13)					
Increasing competition (14)					
Government regulations and compliance (red-tape) (15)					
Lengthy project approval processes (16)					
Environmental compliance (green-tape) (17)					
Environmental regulatory uncertainty (18)					
Current infrastructure bottlenecks (19)					
Future infrastructure					

	Insignificant limitation (1)	Slightly significant limitation (2)	Moderately significant limitation (3)	Very significant limitation (4)	Crucial limitation (5)
availability uncertainty (ports, rails, etc) (20)					
Social licence to operate (Land access, community relations) (21)					
Other (Please specify) (22)					
Access to overseas labour (23)					
Immigration processes (24)					
Mandatory reporting and disclosure (25)					
Changes to employee allowances and concessions (26)					

Q41 Please count innovation as occurring when a new or significantly improved manufactured product, or service product, is introduced to the market ("product innovation"), or when a new or significantly improved production, or delivery method, is used commercially ("process innovation"), and when changes in knowledge or skills, routines, competence, equipment, or engineering practices are required to develop or make the new product, or to introduce the new process.

Please do not count as product innovation, changes which are purely aesthetic (such as changes in colour or decoration), or which simply involve product differentiation (that is minor design or presentation changes which differentiate the product while leaving it technically unchanged in construction or performance). The implementation of a quality standard is not innovation unless it is directly related to the introduction of technologically new, or significantly improved, products or processes

Q40 **INNOVATION INTRODUCTIONS** Has your firm introduced any of the following technology, service, or managerial innovations in the past 3 years?

	Introduced innovation in past 3 years?		Was the innovation new to your firm AND to the industry?		Was the innovation only new to your firm?	
	Yes (1)	No (2)	Yes (1)	No (2)	Yes (1)	No (2)
Technologically new or significantly improved physical product / technology (1)						
Technologically new or significantly improved methods of producing a physical product / technology (2)						
Technological improvements in supply, storage or distribution systems for physical product / technology (3)						
New or significantly improved ‘service product’ (4)						
New method to produce and deliver your ‘service product’ (5)						
New organisational/ managerial process or marketing methods (6)						

If NO innovations (6 NOs in column 2) then end survey.

Q62 If Yes, please describe in a few words your innovation and the value generated/anticipated?

Q63 Please attribute your Australian organisation's revenues derived from the following types of innovation in the past introduced within the last three years?

______ Unchanged or only marginally changed products or services (1)

______ Significantly improved products or services (2)

______ Brand new products or services introduced within the last 3 years (3)

Q64 How were your innovations developed in the last 3 years? (tick the most appropriate)

______ Mainly within your firm or firm group (1)

______ Mainly in collaboration with other firms or institutions (2)

______ Mainly adopted after development by other firms or institutions (3)

______ Adopted from parent firms (4)

Q65 Has your organisation been involved in one or more of the following activities, in the last 3 years?

	Yes (1)	No (2)
Filed for patents, trademarks or service marks (1)		
Out licensed (Licensed patents or technical information directly TO ANOTHER PARTY) for a fee, or royalty payments, or other type of compensation? This includes any arms-length relationships like JVs or subsidiaries) (2)		
Shared technical details openly to the industry to spur subsequent innovation or adoption of technology (e.g. any way real technical detail is shared externally but with no immediate direct monetary benefit) (3)		
Shared technical information via confidentiality agreements in order to explore potential larger partnerships or licensing opportunities (4)		
In-licensed patents or other intellectually property FROM another entity (5)		

Q66 SOURCES OF INNOVATION INFORMATION

Please indicate the importance of the following internal sources (these include management, production, research & development (R&D), sales and marketing functions) and/or external sources of information for your firm's innovation activities during the last 3 years. Please circle the appropriate number in each row.

	Not a source (1)	An insignificant source (2)	A common source (3)	Very significant source (4)	Crucial source (5)
within the firm (1)					
within the group (if you have subsidiary or associated firms, or from JV parents) (2)					
Suppliers of equipment, materials and components (3)					
clients or customers (4)					
competitors in your line of business (5)					
consultancy firms (6)					
financiers (e.g. venture capitalists) (7)					
universities/higher education institutes (8)					
government or private non-profit research institutes (9)					
patent disclosures (10)					
professional conferences, meetings, professional journals (11)					
fairs/exhibitions (12)					
trade associations, chambers of commerce (13)					
computer-based information networks (14)					

Q67 We sincerely appreciate your taking the time to answer these questions. If you have any questions, or would like to see the results of the survey, please phone: +61 7 3346 8160, or email: m.verreynne@business.uq.edu.auAPPROVED BY THE UNIVERSITY OF QUEENSLAND BEHAVIOURAL & SOCIAL SCIENCES ETHICAL REVIEW COMMITTEE, on 6th November 2009 for a period of five years, Reference Number 2009001621.