

Transforming innovation systems in emerging
economies: an evolutionary study of the
Brazilian petroleum industry

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Abstract

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The thesis is submitted under the alternative format, comprising three papers. The key theoretical contribution of the thesis can be found in each of these papers. First, the thesis explores the relationship between national and sectoral systems of innovation, and emphasises the need for governmental policies at each level to be both coordinated and complementary. Second, it offers an examination of the emerging role of universities in innovation systems, which far exceeds the traditional perspective of universities as 'knowledge suppliers' and the more recent notion of the 'entrepreneurial university'. Finally, it offers insight into the strategies of foreign MNEs under the context of industry clusters.

The thesis discusses the development of the Brazilian petroleum innovation system following one of the largest oil and gas discoveries in the Americas for decades. The pre-salt oil reserves were discovered in 2007 and are estimated to amount to at least the 60 billion barrels of oil in the North Sea. They are located off the south-eastern coast of Brazil in ultra-deep water (i.e. depths greater than 1500m) and are named as such because they reside under a thick layer of salt (up to two kilometres in depth). The location of the reserves adds great complexity to the challenge of their extraction. It also offers opportunities for competitive advantage to those actors within the innovation system who successfully innovate in addressing this challenge.

The study draws upon an empirical investigation that included forty-five in-depth interviews, conducted in 2014 and 2015, and is supplemented by documentary analysis. These interviews were largely held with governmental agencies, public universities and petroleum-focussed enterprises (both domestic SMEs and global MNEs). Each group of actors are discussed in a different empirical paper: the efforts of governmental regulatory agencies in creating innovation in Brazil's national petroleum industry; the evolving role of public universities in pursuit of technology transfer and academic entrepreneurship; and the R&D strategies of several global oil and gas MNEs that have taken residence in the recently-established industry cluster in Rio de Janeiro.

The thesis also offers much to practitioners: guidance for the enactors of innovation policy following a large natural resource discovery; a model for universities wishing to develop a portfolio of entrepreneurial support, which has been shown to greatly support a university's own technology transfer objectives; and direction for foreign MNEs in how to adapt to changes in industry clusters. The need for and challenge of achieving cooperation between diverse actors in an innovation system are apparent throughout the thesis. This cooperation is even more important in emerging economies such of Brazil, which often suffer from a lack of coordination between actors.

Declaration

I, Alec Waterworth, declare that no portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

I further declare that for the three papers which constitute the body of this thesis, I carried out the entirety of the ideation and drafting of the material.

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Chapter 1: Introduction

Innovation can be defined as the introduction of new or changed products, services or organisational forms to a marketplace, or more succinctly as the commercialisation of new ideas (Simmie, 2008). Innovation is a cumulative phenomenon, whereby “one (important) innovation tends to facilitate (induce) other innovations in the same or related fields” (Fagerberg, 2005). This dynamic fosters marked growth in the sector and country in which the innovation occurs (Tinguely, 2013). In this regard, innovation plays an important role in economic growth and is today recognised as the leading driver of economic change. Maddison (2001) illustrates this in comprehensively examining the economic history of the periods preceding (the year 1000 to 1820) and following the Industrial Revolution (refer also Freeman and Soete, 1997; Maddison, 1995). It would now seem “beyond dispute that a change of technology in the pure sense, coupled with organisational changes at various levels of aggregation, are the main driving factors behind the continuous increase of living standards entailed by this process” (Verspagen, 2005).

Within developing countries, innovation is therefore a vital element to industrialisation and ‘catch-up’ (that being, the ability of a country to narrow the productivity and income gap with respect to a leader country; Fagerberg and Godinho, 2005). Wealth disparity between the richest and poorest nations of the world has increased greatly over the last two hundred and fifty years, growing from 5:1 to 400:1 today (Landes, 1999). Despite this enduring trend of growing disparity between developing and developed economies, there are nevertheless many examples of once underdeveloped countries successfully achieving catch-up. Fagerberg and Srholec (2005) offer the United States and Germany as examples of now established world leading economies that were once on a catch-up trajectory, along with Japan in the decades around the Second World War and, more recently, the ‘Asian tigers’ (Hong Kong, Singapore, South Korea and Taiwan).

As noted by Fagerberg and Godinho (2005), success stories of catch-up such as Germany, the United States and Japan did not achieve economic growth by merely imitating the more advanced technologies of leader countries (refer Freeman, 1987; Freeman and Soete, 1997; Freeman and Louçã, 2001). Taking the example of Japan, the country’s strategy changed during the catch-up process, from one of technology imitation via foreign direct investment (FDI) to one of indigenous innovation (Kim, 1997). This allowed the country to limit the role of FDI in the catch-up process over time (Liu, 2005; cited in Tang and Hussler, 2011). However, for a country like Brazil (which, despite considerable growth over the last two decades, is still far from achieving catch-up), FDI has been instrumental in getting the country

to where it is, and the country is yet to demonstrate the kind of capacity for indigenous innovation that can historically be observed in catch-up success stories.

The challenge for the governments of developing countries in pursuit of catch-up is how to transition from technology imitation to indigenous innovation. This requires an effective system of institutional and governance structures, investment in higher education as a source of knowledge generation, and the presence and R&D-focussed investment of collaboratively-engaged foreign MNEs. These three pivotal tenets of a well-functioning system of innovation are the focus of the three papers presented in this thesis.

With regards to the macroeconomic focus of the study, the case study country, Brazil, can be considered both as a developing country and an ‘emerging economy’. An emerging economy is one that is considered to currently be in transition between developing and developed country status. The notion of emerging economies can be traced back to the early 1980s, when the term ‘newly industrialised countries’ was used to describe nations that are yet to reach developed country status but are experiencing rapid economic growth. The term was used particularly in respect to the liberalisation of Asian and Latin American markets that was occurring at the time. It has since been superseded by the broader term ‘emerging economies’, following the adoption of market-focussed policies by most developing countries (Hoskisson et al., 2000). Although no commonly accepted definition has been reached for the term, Arnold and Quelch (1998) identify three aspects of a country’s economy that are consistent among various definitions:

- The absolute level of economic development, typically indicated by the gross domestic product (GDP) per capita;
- The relative pace of economic development, usually indicated by GDP growth; and
- The system of market governance, particularly the extent and stability of a free-market system. A country in the process of economic liberalisation is often referred to as a ‘transitional economy’.

Many researchers and research organisations have offered listings of the world’s emerging economies, the most popularised of which are the BRIC countries: Brazil, Russia, India and China, which were identified by O’Neill (2001) as future economic powers. O’Neill would later identify a further eleven emerging economies (termed the Next Eleven, or N-11) – Bangladesh, Egypt, Indonesia, Iran, Mexico, Nigeria, Pakistan, the Philippines, Turkey, South Korea and Vietnam – that have the potential to collectively rival the G7 (Canada, France, Germany, Italy, Japan, the United Kingdom and the United States) in the future (Lawson et al., 2007).

Whereas in the last century technological advancement was limited largely to Western Europe, the United States and Japan, emerging economies such as the BRICs are increasingly demonstrating a capacity for innovation. As with the leader countries before them, the BRICs are enjoying economic growth as a result of increased innovation activity. There is evidence that these countries are looking beyond the typical model of utilising foreign sources for innovation to opportunities for indigenous innovation (Fu and Gong, 2011; Tang and Hussler, 2011).

Of course, this transition in the innovation strategies of emerging economies has been observed before (e.g. in post-War Japan). However, given the size of the BRIC countries, and in contrast with the recent ascension of the Asian tigers, the implications for the global economy are considerably greater. The BRICs have the growth potential to individually rival leader countries in the developed world in the future. Successful and sustained fostering of innovation in these economies would have major implications for the developed world: both positive (e.g. increasing expertise bases, technology sources and collaboration opportunities) and negative (e.g. increasing trade competition, threats to market integration and technological leadership).

The emergence of these economies can provide valuable lessons to other developing nations with regards to guiding and promoting the growth process (Fu et al., 2011). The BRIC countries have, to varying degrees of success and through different strategies, placed an increasing emphasis on indigenous innovation. The experiences of emerging economies thus have much to offer a broader group of global developing countries: those perhaps lacking the scale to catch-up but nevertheless with the potential to develop their domestic innovation capacity. Whilst the primary case study of the thesis is an emerging economy, this scope was established with confidence that the findings and conclusions of the study would have implications for a wider group of actors.

Growth in the BRIC countries has slowed in recent years – observed, for example, in the bursting of the Chinese property bubble and the deep recessions currently gripping Brazil and Russia – with the long run underlying growth rate of the BRICs falling from 8 per cent to 6 per cent since 2010 (Davies, 2015). However, the decline in growth in the BRICs is in line with the economies of developed countries and, therefore, their share of global growth has remained roughly the same. Further, economic stagnation in some of the BRICs – namely Brazil and China – falls some way short of those experienced by these countries respectively in the 1980s and late 1980s and 1990s (IMF, 2013). Forecasts from the World Economic Outlook (which, it should be noted, are consistently optimistic) suggest that Brazil and India will enjoy growth in line with (or higher than) their average of the past fifteen years, although China and Russia's will be markedly lower (ibid). Although at present the outlook for these countries may not

seem as positive as it once did, when considered in light of global economic trends, the BRIC countries remain relevant to the discussion of potential future economic powers.

With regards now to the three core foci of the thesis' three papers, it is important to note that, whilst these mirror Leydesdorff's (2000) 'Triple Helix' – the three pillars of innovation: industry, government and academia – this was not an extant objective of the study. Rather, the starting point for scoping potential avenues of investigation was simply the desire to study innovation in an emerging economy setting. Emerging economies provide a compelling context for the study of innovation for several reasons. First, the last decade has seen increasing attention being paid to emerging economies (primarily the BRIC countries) from researchers in the field of economics, concerning not only their rapid economic growth but also their increasing capacity for indigenous innovation. This alone makes the study of innovation in emerging economies an attractive prospect. Secondly, all countries face similar challenges in innovating, outlined by The World Bank (2010) as: the provision of appropriate financial and other measures; the removal of regulatory, institutional or competitive obstacles to innovation; and strengthening the knowledge base through investment in education and research. However, this challenge is heightened in developing and emerging economies, where the availability of investment capital is generally lower and the knowledge base of the country will be considerably less developed. Studying how emerging economies address this challenge, despite these limitations, was an intriguing proposition and one that would also lead to insights of relevance to a broader group of global economies.

Finally, whilst indigenous innovation in emerging economies has been addressed in the literature, the focus has largely been on domestic MNEs, their potential to rival or even surpass their developed world counterparts in certain industries, and the strategies utilised and challenges faced in achieving this (refer, for example, Bonaglia et al., 2007; Gammeltoft et al., 2012; Lynch and Jin, 2016; Nolan et al., 2008; Ramamurti, 2009; van Agtmael, 2007). In this study, interest was drawn instead to the potential for indigenous innovation from small and medium-sized enterprises (SMEs) within such a context (a subject considerably less addressed in the literature), the success of which would require the involvement of and interaction between many more actors. As such, the systems of innovation theory was an ideal framework with which to shape the research focus and conduct analysis thereafter.

The aforementioned three central tenets of an effective system of innovation were identified and formed a starting position from which to explore a systemic view of emerging economy indigenous innovation. The systems of innovation literature emphasises the role of government and policy in shaping innovation systems (e.g. Freeman, 1987; Edquist, 1997; Edquist et al., 2004; Teubal, 2002). Tackling the innovation challenge outlined by The World Bank (2010)

above is regarded as the responsibility of government, as best addressed through effective innovation policy decisions. The role of government in this regard is well sketched in the literature. However, a review of the literature revealed an opportunity to explore this policy challenge through the relationship between two systems of innovation at different levels of analysis (a national and sectoral system of innovation), whereby the government traverses both systems.

This potential focus for investigation was considered further in light of prospective case studies in emerging markets. Energy markets were initially selected as typically high-innovation sectors. However, this also raised the issue of nationalised industries in cases such as CNPC and Sinopec in China, and Rosneft in Russia. There was one leading example however in Brazil. Although the national petroleum champion, Petrobras, was privatised in 1997, it is still majority-owned by the Brazilian government and the industry is otherwise vital to the national economy (with Petrobras alone accounting for 13 per cent of total GDP; Petrobras, 2016). It is entrenched in the country's political history, and an inherent part of the national identity. Brazilian petroleum is a vital component of the country's national system of innovation, thus making it an interesting case with which to examine the relationship between national and sectoral systems of innovation. Given the relatively recent discovery of vast offshore oil reserves in Brazil (termed the 'pre-salt', as the reserves reside under a thick salt layer below the seabed), this provided an ideal framing for the study. The pre-salt has tremendous potential as both a driver for economic growth and as an impetus for the generation of indigenous innovation. The country's leadership has referred to the pre-salt as such: at the time of the reserves' discovery, then-President Luiz Inácio Lula da Silva stated that the "pre-salt resources, if well administrated, can be a catalyst for great transformations in Brazil" (Wertheim, 2009), with President Dilma Rousseff (at that time Secretary of State) labelling them Brazil's "passport to the future". This established the Brazilian pre-salt scenario as the setting for the study, and the governmental policy dilemma between national and sectoral development as the focus of the first paper of the thesis.

The systems of innovation literature similarly emphasises the crucial role of universities and research institutes, not only as a source of knowledge generation but also as a source of technology transfer and, more recently, entrepreneurship. This role has been addressed extensively within the literature, albeit largely concerning developed country universities. However, early research into the Brazilian case revealed that this traditional perspective of the entrepreneurial university is being far exceeded by several of country's leading universities. This includes a broad and far-reaching array of initiatives, supporting firms in their growth as well as creation, and a much greater emphasis on entrepreneurship education, under a remit of

socioeconomic betterment. This created an opportunity to conduct research at these universities so as to capture the additional mechanisms, roles, drivers and outputs of this emerging entrepreneurial university model, given that this recent development has received scant attention from researchers. A second line of inquiry concerns the broader considerations of academic entrepreneurship as an explicit strategy of emerging economy universities: whether this is a case of imitation (of developing world models) or a novel endeavour; and how 'bottom-up' mechanisms such as these align with, but also address the shortcomings of, governmental innovation policy (i.e. 'top-down' mechanisms). This is the focus of the second paper.

Successful technological change and catch-up within emerging economies requires R&D-focussed investment from foreign firms (Fu et al., 2011). In recognising this, the Brazilian government has established incentives for foreign companies to establish R&D facilities in Brazil. Given the scale, and hence potential market, of the pre-salt reserves, several leading global petroleum equipment and services providers have duly obliged. This is most apparent in Rio de Janeiro at the science park of the Federal University (UFRJ), as was initially evidenced first-hand during a fieldwork visit to Brazil in May 2013. Whilst several of the eight now inaugurated foreign MNE technology centres in the science park were still at the planning or construction stage, the site was no less impressive: enormous R&D centres for some of the biggest names in global petroleum, all within walking distance from one another. Moreover, it was clear from the pilot interviews that there was a great deal of optimism around what this investment could mean for the university and domestic firms hosted in the science park and adjoining business incubator (and therefore indigenous innovation). This presented a fascinating case for investigation.

The oil and gas industry changed considerably between the first fieldwork visit in 2013 and that in 2015, due to severe changes in both global conditions (i.e. the oil price crash) and domestic conditions (the Petrobras scandal). It has created a very different environment for innovation in the science park. This led to an investigation of the changing dynamics within the science park (and therefore, more broadly, industry clusters; Porter, 1990; 1998), and how this had impacted the R&D strategies adopted by the MNEs subsidiaries. This is the focus of the third and final paper in the thesis.

Whilst the three papers address three distinct bodies of literature, these are nevertheless framed within the broader discussion of the Brazilian national innovation system and share common theoretical constructs with one another. The Triple Helix, with its three interrelated core components of a national system of innovation – government, academia and industry – is useful in graphically representing this (refer Figure 1).

Systems of innovation theory is the primary research framework that underpins the study. A comprehensive overview of the theory is presented in the first paper of this thesis. The approach focuses on the analysis of institutional frameworks and innovative capabilities of countries (Freeman, 1987; Lundvall, 1992; Nelson, 1993), sectors (Malerba, 2003; 2004; 2005) and regions (Asheim and Gertler, 2005; Cooke et al., 1997). The decision to frame the thesis through the systems of innovation theory was made for several reasons. Arocena and Sutz (2005), in outlining four strengths of the approach, provide a useful framework for this discussion:

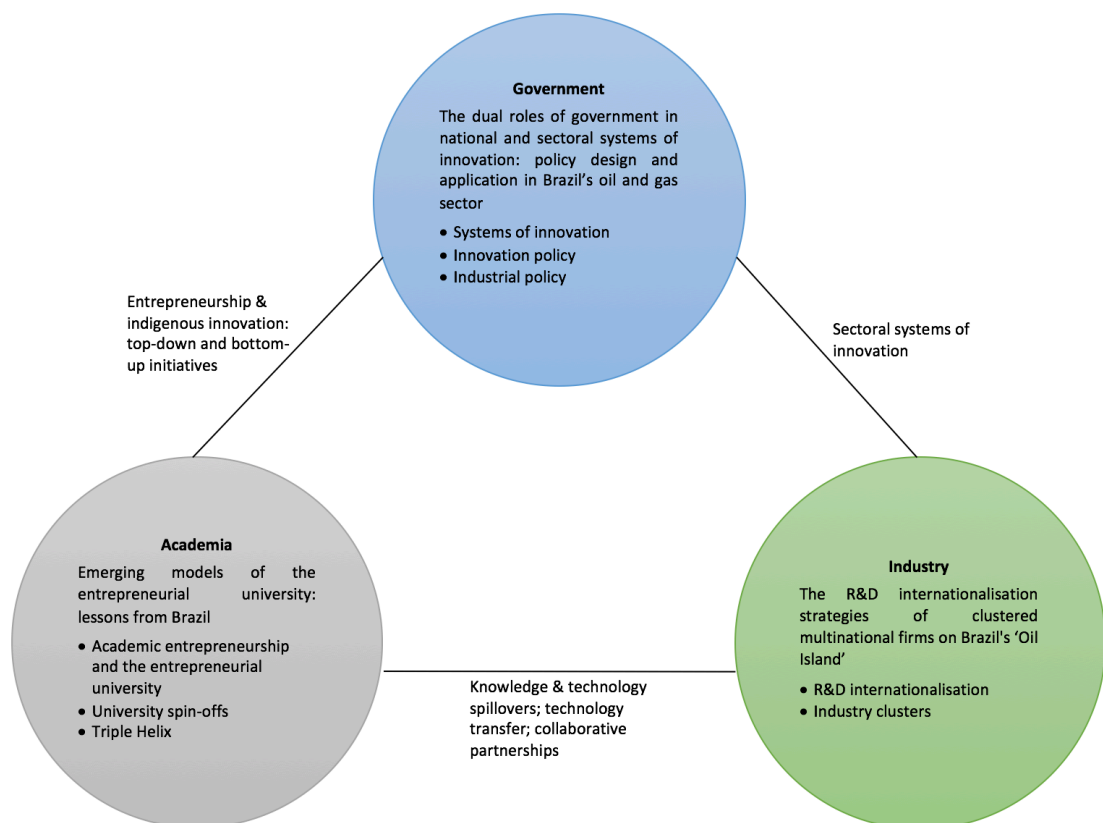


Figure 1: A Triple Helix perspective of the Brazilian National Innovation System

- i. It highlights the significance of numerous diverse social actors, thus going beyond the 'state or market' dichotomy.

The research draws attention to the broad range of actors that contribute to the innovation process. This includes state actors (industry regulatory bodies, and national and state funding bodies) and market actors (foreign MNEs, as a source of technology transfer and collaboration, and domestic firms and entrepreneurs, as drivers of indigenous innovation efforts). Crucially, the theory also captures the impact of bottom-up initiatives (those emanating from universities and public research institutes) on the innovation process, which is the focus of the second paper.

It is therefore an effective framework for capturing and analysing the role of these diverse actors, some of whom might be disregarded if observed through other approaches.

- ii. It directs our attention to some concrete processes of interactions between actors and organisations, offering a general frame for their study.

The importance of interactions between different and diverse actors is emphasised throughout the systems of innovation literature. These interactions are at the core of the analysis presented here and this is therefore the theory's most valuable contribution to the thesis. It provided guidance at the data collection stage as to how to structure the investigation of the actors' interfaces and exchanges within the system, and further offered a basis for data analysis in each of the three papers. It captures not only the interactions between actors but also the multitude of factors that underlie and shape these interactions. The strength of these interactions, both within and between systems of innovation, is fundamental to successful and sustainable technological progress.

- iii. It focuses not only on economic matters but also on political, institutional and cultural issues.

As highlighted by Chesnais and Sauviat (2003), the systems of innovation approach places considerable importance on the historical, political and economic trajectories of the system in question. The research demonstrates that a country's political and socioeconomic history and present-day conditions influence the decision-making of a system's actors. This is most clearly evident in the first paper, although is apparent in all three. Macroeconomic, political, institutional and financial considerations are particularly important in analysing the innovation systems of less-developed countries, which often face significant constraints to innovation pertaining to these considerations, such as hyperinflation, high external debt and high interest rates (Lastres et al., 2003).

- iv. The three preceding potentialities of the theory pave the way for a fourth and fundamental one: it is a tool for studying the concrete aspects of innovation activities in underdeveloped/developing countries.

The systems of innovation approach is centred on the notion that innovation occurs differently in different contexts (be it countries, regions, sectors or technological groups). The theory emerged from studies of the developed world. Investigations of the developing world remain less common to this day. Moreover, there have been few attempts to apply the systems of innovation concept to emerging economies. The theory has nevertheless proven, post-ante, equally suitable to developing world case studies and capable of capturing the idiosyncrasies

of such contexts. Understanding economic growth and the pursuit of catch-up in emerging economies requires an insight into the behaviour and needs of a system's actors, and an appreciation of the unique economic, technological, institutional, political and cultural factors that influence it (Freeman and Louçã, 2001). The systems of innovation approach supports such an investigation. These contextual considerations are pivotal to several of the key findings of the thesis.

Whilst the four considerations of Arocena and Sutz (2005) have been discussed with respect to national systems of innovation, the first three are equally applicable to sectoral systems of innovation. The “innovation systems” of the thesis title is in reference to both the case study sectoral system, and the ramifications and broader consequences that this holds for the national system under which it resides.

Following the subsequent discussion of the overarching research methodology of the thesis, each paper will be presented in turn. This will be followed by a concluding chapter that summarises the key findings from each, the broader contributions of the thesis, the limitations of the research and opportunities for future investigation.

Research Methodology

The decision was made early on in the study to adopt a case study approach. As a research strategy, case study enquiry supports the detailed investigation of a phenomenon over a period of time within the context under which it occurs, and aims to provide an analysis of the context and underlying processes that elucidate the theoretical considerations under examination (Hartley, 2004). Qualitative methods such as this are concerned with the meaning rather than the frequency of a phenomenon, which is clearly aligned with the research focus of this thesis.

A multiple case study approach was adopted for several reasons. First, it supports a detailed and holistic investigation of complex social processes (e.g. the actors, interactions and underlying institutions in a system of innovation) within their real-life context, thus enabling the discovery of the answers to ‘how’ and ‘why’ questions (Hartley, 2004; Yin, 2003). Secondly, it allows for the use of multiple forms of data collection (Creswell, 1998). In this case, two data sources – semi-structured interviews and documentary analysis – were selected and used in a complementary manner. Thirdly, it is effective in supporting the identification of causal mechanisms behind a phenomenon, which can “explain the presumed causal links in real-life interventions that are too complex for the survey or experimental strategies” (Yin 2003). Finally, the extended period of study for this thesis led to the research focus changing in light of the fieldwork process, and new areas of investigation otherwise arose. The flexibility

of case study research (Robson, 2002) to “adapt to and probe areas of planned but also emerged theory” (Hartley, 2004) was also regarded as a considerable advantage.

Case studies have been conceptualised differently by different authors with regards to their focus, structure, choice of research methods and, particularly, the role of theory (Merriam, 1998; Stake, 1995; Yin, 2003). The methodology across all three papers can be characterised as a qualitative, multiple case study approach (refer Yin, 2003). However, the continuum also offered by Yin (2003) of exploratory, explanatory and descriptive is also useful to describe the research strategy, although no one category describes the research as it was conducted throughout the study. Three periods of fieldwork study took place in Brazil. The first, comprising a small set of pilot interviews, can be considered exploratory research, whereby the phenomenon being investigated, at that time, had no clear, single set of outcomes. The second period of fieldwork study can be regarded as lying somewhere between exploratory and explanatory research, whereby research questions and hypotheses had been formulated but there was a high degree of uncertainty as to the outcomes of the research. The final fieldwork visit was largely explanatory – gathering further evidence in support of answering the research questions and the now substantiated hypotheses – although with some exploratory work with regards to the third paper.

As a research strategy, case studies can be purely qualitative, purely quantitative or can be explored through a mixed methods approach. The decision to adopt a purely qualitative approach – namely through interviews and documentary analysis – was driven by the strength of these methods in addressing explanatory (i.e. ‘how’ and ‘why’) research questions (Hartley, 2004; Yin, 2003) and their suitability to capturing the meaning behind a phenomenon. By extension, an exclusively quantitative approach would not have been suitable for this study. However, the use of several quantitative methods in addition to the abovementioned qualitative methods was considered (i.e. a mixed methods approach). Two quantitative methods were given particular consideration. First, surveys were considered in the early stages of the research project, by way of gathering data in an exploratory fashion to support the formulation of conceptual frameworks and hypotheses for the three papers. However, given that relatively little was known to the author of the social dynamics of the Brazilian petroleum innovation system – a subject of few English-language publications – there was a lack of clear variables to examine in the early stages of the study. Therefore, although pilot interviews concern far fewer potential subjects, the exploratory nature of these interviews with academic experts proved a superior choice in identifying and elucidating areas for further investigation regarding these variables. Similarly, in the latter stages of the project, where the focus of the research

shifted to an explanatory focus, survey data was unlikely to contribute to the discussion of these variables with the effectiveness of interviews.

Social network analysis – a strategy for investigating social structures (Otte and Rousseau, 2002) – was also considered. By gathering patent data as a representation of R&D activity within Brazilian petroleum, it was conceived that the interactions between the actors of the system of innovation could be mapped and analysed. However, this was not utilised for several reasons. First, an approach of this nature is focussed on the question of ‘who’ rather than ‘why’ and ‘how’, and whilst this would add some contextual detail to the discussion, it does not address the primary focus of the thesis. The question of ‘who’ is of greater significance to the third paper, where the analysis is spatially bounded within a regional agglomeration and concerns issues of proximity. However, this would present problems with regards to isolating just those patents that emerge from this geographical area. This is discussed further in the paper. Secondly, there is a significant delay between the act of innovation, the generation of the patent and it then becoming publicly available (refer Gök et al., 2015). Given the accelerating pace of growth in Brazilian petroleum over the last decade, this raised concerns as to the currency of patent data and how this might misrepresent the current landscape in the industry. Interview data raises no such concerns. Finally, social network analysis was otherwise rejected due to the anticipated time expenditure that would be required from such an analysis.

A purely qualitative approach was adopted, with face-to-face interviews selected as the primary research method. Documentary analysis was utilised as a complementary research technique to the interviews, providing more detail around the areas of discussion, rather than validating the discussion points themselves. However, specific details in interviewees’ statements (e.g. the financial details of a company’s R&D expenditure, or the specifics of industry regulations, etc.) have been verified through documentary sources wherever publicly available. All interviews were conducted in a semi-structured manner, which was selected as it grants the subject flexibility in their response and supports the gathering of detailed contextual information, whilst also provided a reasonable degree of structure to the discussions. Documentary research was conducted around each interviewee and/or their organisation in the days prior to an interview, which formed the basis for any interviewee-specific discussion topics or questions, the inclusion of which is also supported by the semi-structured approach.

Interviewees were selected through ‘non-probability sampling’, whereby subjects are “deliberately selected to reflect particular features of, or groups within, the sampled population” (Ritchie et al., 2003). Subjects were identified primarily through documentary research, which discerned key actors within the innovation system (and key locations), as well as leading

academic experts and important collaborative partnerships within Brazil. Six groups of actors relevant to the research questions of the study were identified: domestic SMEs; MNEs (Petrobras and global equipment and services providers located in Brazil); academic experts (within energy economics and petroleum engineering); governmental bodies (regulatory and funding organisations); non-government industry organisations; and the management of university science parks and business incubators. Subjects were selected within these groups on the basis that they could offer a unique and detailed perspective on the phenomenon. Primarily, this can be characterised as ‘purposive sampling’, or a sub-category of which, ‘theoretical sampling’, whereby subjects are selected on the basis of their potential to contribute to theory development (refer Ritchie et al., 2003). However, given that fieldwork was only carried out in three regions of Brazil, there was an element of ‘convenience sampling’, whereby subjects are selected because of their accessibility and proximity to the researcher. Sampling continued until each group’s perspectives had been adequately captured in consideration of the study’s research questions.

Interviews were requested by email prior to arriving in Brazil but, where unsuccessful, this was followed up by visiting the offices of the respective organisations during the visit. All interviewees were issued an electronic copy of the ‘Participant Information Sheet’ (refer Appendix 1) at the time of requesting an interview by email, and were further provided a hard copy at the start of the interview. All interviewees signed a hard copy of the ‘Consent Form’ (Appendix 2) at the start of the interview, which was retained by the researcher. An electronic copy of the signed Consent Form was sent via email to the respective interviewee within the 24 hours following the interview.

Interviews took place over three periods during the doctoral study. First, three pilot interviews were conducted in Brazil in May 2013 with leading researchers in the field of energy economics at UFRJ’s Institute for Graduate Studies and Research in Engineering (COPPE). This brief visit to Rio de Janeiro was combined with attendance at a workshop on ‘Research and Graduate Programs in Public Policy: Building International Networks’, hosted by the Federal University of Paraná. The pilot interviews were held primarily for three reasons: to test early propositions with experts in the field; to gain further insight into the history and current state of Brazilian petroleum and how this has been entwined with Brazil’s political landscape over the years; to further identify key actors in the systems of innovation; and, finally, to trial the effectiveness of the semi-structured interview approach and the topics and questions for discussion.

In April 2014, a second fieldwork trip was made to Brazil. The country’s oil and gas industry is largely centred around Rio de Janeiro and, as such, three of the five weeks were spent in Rio. Having recognised COPPE as a major source of innovation and a crucial collaborative partner

of Petrobras, an initial set of interviews were conducted with various actors on the university's campus (including the university's science park and business incubator). This included eight SMEs, four of which were located in the incubator, the others being located in the science park. These firms were selected on the basis that petroleum was a key market for the firm (but not necessarily their sole or primary market). Contacts within the management structures of the business incubator and science park also assisted in providing contact information of prospective interviewees. In each case, a director of the company was interviewed.

In addition to this, three technology managers were interviewed from CENPES (Petrobras' primary R&D facility, located on the university campus) and two technology managers from a global oil and gas equipment and services provider (anonymity requested by the interviewees) with a large technology centre in the university's science park. Access to the other resident MNEs within the science park proved problematic during the 2014 visit, despite the best efforts of the researcher to make contact with these firms (both prior to and during the visit).

Whilst still in Rio, of the other three groups of actors, representatives of the industry regulatory body ANP (National Agency of Petroleum), national funding body FINEP (Financier of Studies and Projects) and non-government industry organisation ONIP (National Organisation of the Petroleum Industry) were interviewed, along with academic experts in petroleum engineering at COPPE and another expert in energy studies at UFRJ, as well as the managers of the COPPE business incubator and UFRJ science park.

Away from Rio, the decision was made to continue to focus on university business incubators and science parks as a plentiful source of ambitious, technology-driven firms. Similar potential case studies were sought in other locations in Brazil. Internet-based research revealed a further four potential locations with academic experts, university spin-offs and/or MNE technology centres that were of interest. Of these four cities – São Paulo, Campinas, Salvador and Minas Gerais – the first three were selected based on the availability of potential interview subjects. In the city of São Paulo, two academic experts in energy studies were interviewed at the University of São Paulo (USP). A day-long visit was also made to the university's world-leading subsea laboratory, TPN, which also hosts a USP spin-off, Technomar, within its premises. A professor from the former and two directors from the latter were interviewed about this ongoing collaboration. One further interview was held with the director of an SME within the university's business incubator, Cietec.

Still within the state of São Paulo, the state's second city, Campinas, was the source of six further interviews. Two academic experts in the field of energy studies were interviewed from the University of Campinas (UNICAMP), along with the founder of a new university spin-off,

InReservior, at the university's incubator. Away from the university, internet research revealed the presence of a start-up, Adest, who, despite the size of the company, had attracted interest from two leading global operators, including Petrobras. The founder of this company was interviewed, along with the lead researcher at the partner laboratory in Campinas, the Brazilian Synchrotron Light Laboratory (LNLS). The founder of Adest also kindly made arrangements for an interview with a former colleague and now director of another SME in the city, Simworx. This is known as 'snowballing' within the literature, and was invaluable in both identifying several potential interview subjects and in recruiting those subjects.

The final destination in Brazil in 2014 was Salvador, in the state of Bahia. Interviews were scheduled with a technology manager at Petrobras, the directors of two spin-offs from the state's Federal University of Bahia (UFBA) and two academic experts from the university's energy studies department. Arrangements were also made to visit a large research institute, Senai-Cimatec. Unfortunately, only a day after arriving in Salvador, a police strike shut down the city for several days, meaning only the visit to Senai-Cimatec was completed.

A further three-week fieldwork trip to Brazil was made in May 2015. In reflection of the interview data collected from 2014, it was clear that every effort needed to be made to attain interviews with petroleum MNEs in the country; particularly those residing in UFRJ's science park. As such, the entirety of the visit was spent in Rio de Janeiro. All existing contacts were utilised in an attempt to contact MNEs in the city, which proved far more successful this time around. Of the eight MNE technology centres that are currently hosted at the UFRJ science park, seven were inaugurated as of May 2015. The technology managers of five of these agreed to be interviewed (which included revisiting the anonymised MNE from the previous year). This was further supplemented by interviews with three other MNEs in the city, as well as the directors of two incubated SMEs, one academic expert in energy studies, and one non-government industry organisation, SEBRAE (Brazilian Support Service for Micro and Small Enterprises). Since the previous year, the composition of firms in the science park and the funding landscape of Brazilian petroleum had changed considerably. The management of the park and representatives from funding body FINEP were therefore interviewed again.

A draft interview protocol for each group of actors was initially developed following a review of the relevant literature, prior to the pilot interviews in May 2013. This was revised ahead of the fieldwork visit in April 2014, and in reflection of a maturing understanding of the gaps in the literature and changing scenario of the industry. This was further revised in consideration of the resulting interview data, prior to the visit in May 2015. However, the structure of the interview protocol remained largely the same between these latter two periods. The interview

protocol was used to both guide the interviews and also to ease the process by which data from different actors could be compared during data analysis.

For SMEs and MNEs, the interview protocol took the following form:

- i. General information: number of employees, access to R&D facilities, current and future investment, annual R&D budget;
- ii. Technology strategy: significance and direction of investment, how R&D efforts are organised/managed, nature of innovation (adaptive/innovative, research/development/engineering, niche/core, complementarity), drivers and challenges of innovating, main successes to date, determinants of investment, sources of knowledge;
- iii. Environment: benefits of location, share and importance of local expertise, interaction with universities, interaction with the science park/incubator, benefits of proximity (to other actors), drivers of collaboration, importance of collaboration, how collaborative arrangements are organised/managed;
- iv. Industry: significance and effectiveness of government interventions, challenges for domestic firms in the industry, current and future state of Brazilian petroleum.

Interviews with science park/incubator management groups and non-government industry organisations focussed on: the support offered to SMEs; the challenges domestic SMEs face; the significance of collaboration (with universities/other firms); the importance and effectiveness of governmental funding and regulation; and the current and future state of Brazilian petroleum. Interviews with governmental bodies focussed on: the support offered; how this has changed recently, and why; how support is prioritised, organised, managed and delivered; the significance of university collaboration, incubators and science parks; the role of foreign MNEs in the innovation system; any perceived shortcomings in the current governmental interventions; the challenges currently faced by domestic SMEs; and the outlook for the industry. Finally, academic experts, who can be divided into those in the social sciences and those in the physical sciences, were queried, in the case of the former, about their perception of the Brazilian petroleum industry (its challenges, shortcomings, and future), and in the case of the latter, about the interviewee's involvement in collaborative efforts with firms.

In total, forty-five interviews were conducted. A list of interviewees is offered in Appendix 3. Most interviews had a duration of between one and two hours. All interviews were recorded (with the interviewees' permission) and later transcribed into written form so they could be coded and analysed. All interviewees spoke English, thus a translator was not required. Handwritten notes taken during the interviews were subsequently digitised and used to enrich

the interview data and support the coding process. Where interviewees requested to be anonymised (and/or their employer be anonymised), this has been complied with in all cases.

With regards to data analysis, template analysis was used as the primary method of organising the data from interviews and documentary analysis. Template analysis involves organising and analysing data in accordance with a set of themes. These themes are dictated by a template, although one of the approach's strengths is its flexibility. It is an iterative process, which allows the researcher to tailor the approach to the requirements of their particular research project, and modify and re-code the data as they see fit as the data is analysed and interpreted (Brooks and King, 2012). Conversely, the template itself will be modified during the process of data analysis: it is applied in the first instance as the data is coded but revised in reflection of the ongoing analysis. As King (2004) notes, template analysis is effective in examining the "perspectives of different groups within an organisational context". Such a process does not measure the significance of a code or theme by its frequency of occurrence.

Interview data was transcribed within 24 hours of the interview (schedule permitting), to which any supporting information was added. Interview data was not transcribed verbatim. This was primarily because this data would not be used to conduct discourse analysis (i.e. analysing the motivations behind what was said, including non-verbal and emotional cues) and therefore verbatim transcription was unnecessary. The additional time expenditure to the researcher and unavailability of monetary resources to pay for third-party transcription were secondary considerations (Britten (1995) stated that for every hour of audio, 6-7 hours was required for verbatim transcription). Instead, a process of selective transcription and researcher notation was employed (accounting for a time expenditure of around 3 hours for each hour of audio). The reflexive and iterative six-step approach presented in Halcomb and Davidson (2006) offered a useful framework for this and further data collection and analysis activities:

1. Audiotaping of interview and concurrent note taking;
2. Reflective journaling immediately after an interview;
3. Listening to the audiotape and amending/revising field notes and observations;
4. Preliminary content analysis;
5. Secondary content analysis;
6. Thematic review.

With regards to steps 3-6, a document of selective transcriptions and all field notes and supporting documentary information was maintained in Microsoft Excel. This was then coded with respect to the emergent themes in the data (e.g. 'collaboration', 'policy'), and subjects grouped in accordance with their role within the innovation system (i.e. SME, MNE,

governmental body, etc.). Computer-assisted coding was utilised due to its ability to accelerate and assist in the process of managing, sorting and organising large volumes of qualitative data, and retrieval of words and phrases in the data thereafter (Spencer et al., 2003). The software was used to store, code and retrieve the data but this did not extend to any process of automated coding (in acknowledgement of the shortcomings of a mechanistic approach to data analysis described by Bazeley, 2007). The Microsoft Excel document was organised first by the name of interviewee, followed by the time code of the section of the interview, a description of what was said, a broad code for the discussion, and, finally, a more specific set of themes for the discussion. This enabled the data to be filtered by the broader code description, which supported a more comprehensive review of the data within that particular theme, the identification of trends and correlations, and the exploration of evidence relevant to a particular research question or hypothesis. The use of quotes from interviewees in the thesis has been used to underline key findings from the data. Extracting these from the data required the researcher to listen to the audio recordings and transcribe the section of the interview verbatim, as guided by the time code in the Microsoft Excel document.

Content analysis was conducted in two rounds. In the first round (for each of the fieldwork trips), descriptive codes emerged directly from the process of entering the interview data into the Microsoft Excel document. These reflected, in part, the areas for discussion in the interview protocol. This was continuously modified during the process of coding the data, with new codes emerging and existing codes merged or renamed where logical to do so. A second round of content analysis was conducted upon completing coding of the data from the April 2014 and May 2015 fieldwork trips, so as to ensure consistency across the dataset.

Thematic reviews were conducted following completion of the coding exercise from each of the three fieldwork trips. The process was supported by the ability to filter data by code or organisation type and search by keyword in Microsoft Excel, so as to identify themes both within and across organisational groups. The themes were both more specific and more analytical than codes (e.g. 'Petrobras crisis has hindered development', '1% regulation is poorly designed'). These themes were maintained in a further worksheet within the Microsoft Excel document and, as with the codes, added to, amended and merged throughout the study. Each theme was substantiated by a copy of the supporting passage(s) of text from the dataset, the source (e.g. MNE-1) and the time code. Within this worksheet, the themes were grouped by a further broad code (e.g. 'FDI', 'Ilha do Fundao'), thereby bringing together complementary perspectives (either concurring or conflicting) across the different organisational groups. This was then used to form analytical and explanatory accounts to steer the discussion in the thesis in addressing the study's research questions.

List of Papers

Three papers are included in this thesis:

Paper 1 (Chapter 2). Waterworth, A. 'The dual roles of government in national and sectoral systems of innovation: policy design and application in Brazil's oil and gas sector'.

Paper 2 (Chapter 3). Waterworth, A. 'Emerging models of the entrepreneurial university: lessons from Brazil'.

Paper 3 (Chapter 4). Waterworth, A. 'The R&D internationalisation strategies of clustered multinational firms on Brazil's 'Oil Island''.

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Chapter 2: The dual roles of government in national and sectoral systems of innovation: policy design and application in Brazil's oil and gas sector

Abstract

Political and policy contexts are an important determinant in the innovation pathways of countries and their industries. While national and sectoral systems of innovation co-exist, these systems generate differing policy demands. This paper examines coherence and conflict between the policies of co-existing innovation systems and the effects on innovation performance. Case studies from the Norwegian and Brazilian petroleum industries illustrate the competing and often incompatible policy demands of national and sectoral systems of innovation and how these may be reconciled through effective policymaking. The cases illustrate that failure to do so can prove detrimental to sectoral and/or national innovation performance. National government plays a pivotal role as the leading policymaker within both systems. The paper highlights the need for a long-term, coherent approach to policymaking that addresses the potentially conflicting policy demands of co-existing systems.

Introduction

Over the last two decades, researchers and policymakers have embraced systems of innovation theory as an analytical framework for the examination of innovation activities. The concept of national systems of innovation (Freeman, 1998; Lundvall, 1992; Nelson, 1993) portrayed a network of organisations and underlying institutions that facilitate economic growth in a country through technological development and knowledge diffusion. This led to the concept of sectoral systems of innovation (Malerba, 2003, 2004), which focused on specific industrial sectors across national borders. The literature acknowledges the co-existence of systems at different levels of analysis, including at the national and sectoral level (Meuer et al., 2015). Within a given system, the importance of policy complementarities to innovative performance and socio-technical change has also been emphasised (Casper and Soskice, 2004; Coriat and Weinstein, 2004; Freeman, 2002; Malerba, 2005; Soete et al., 2010). The question remains, however, as to the importance of policy complementarities *between* two systems of innovation. This paper proposes that the degree of complementarity between the guiding policies of national and sectoral systems of innovation holds a significant influence on the innovative performance of these co-existing systems.

The paper addresses the relationship between national and sectoral systems of innovation, as illustrated by the policymaking of the national government, as an actor that traverses both systems. A framework for analysing this relationship is put forward, which encompasses the (not necessarily complementary) policy demands of the systems and sketches an intersection between them, within which the government's role is to reconcile these demands. The literature highlights the crucial role of governmental policy in shaping systems of innovation (e.g. Edquist, 1997; Edquist et al., 2004; Freeman, 1987; Teubal, 2002). This intersection is explored through a policy analysis. The paper contends that, whereas the systems of innovation literature perpetuates the notion that systems will co-exist effortlessly, in fact, the competing policy demands of these systems must be decisively addressed to achieve satisfactory national and sectoral innovation performance. The state holds the pivotal role in achieving this through effective policy decisions. The final assertion of the paper is that political and socioeconomic contexts significantly influence the innovation pathway chosen by a country.

The oil and gas industry of Brazil, having recently made one of the largest natural resources discoveries of the last several decades, provides an empirical case for discussion. In 2007, vast offshore oil reserves (termed the 'pre-salt') were discovered in Brazilian oil fields, situated thousands of metres below the seabed, under thick layers of rock and salt. This offers a tremendous technological challenge to the industry but also an opportunity to utilise these reserves to build a domestic sectoral innovative capacity that is currently absent beyond the national oil champion, Petrobras. The scenario is comparable with that of Norwegian petroleum following the discovery of North Sea oil reserves in the late 1960s. In that case, the national government was successful in enacting effective policies to foster innovation in the industry, whilst also ensuring the reserves provided for other economic sectors and improved the country's broader socioeconomic conditions. The Norwegian historical case is utilised here as a benchmark to elucidate the findings from the Brazilian empirical case.

The paper has six parts. The relevant literature will be outlined in the proceeding section, followed by the conceptual framework. The historical context of Brazilian policy intervention is then examined. The fourth section provides further context to the Brazilian case study through a discussion of Norway's development of North Sea petroleum. The current policy and funding landscape of Brazilian petroleum is then outlined. The key findings from the study's fieldwork in Brazil are presented thereafter, followed by conclusions on the wider implications of these findings.

Literature Review

This literature review starts by discussing the theoretical foundations of national and sectoral systems of innovation. This is followed by a discussion of the literature currently available on the relationship between two innovation systems, after which the role of national institutions (and particularly policy) in the development of a system of innovation is also considered. The literature is then summarised and the conceptual framework for the study presented.

Systems of Innovation

When a large natural resource discovery is made, national governments are faced with a dilemma of whether to pursue opportunities for innovation or to simply focus on maximising the nearer-term macroeconomic benefits from exporting these resources. There is a strong research base that indicates that in the long-term, the pursuit of innovation will ultimately lead to a greater degree of economic development. Joseph Schumpeter (1942) considered innovation to be the main driver of economic change. This was substantiated by Solow (1957), who questioned the effectiveness of the existing models of growth at the time, which focused on capital, labour and savings (with a particular emphasis on capital). In a study of the United States between 1909 and 1949, Solow's analysis showed that only around ten per cent of growth could be attributed to capital, whereas the remaining share is derived from technological progress. This was followed by Romer (1986), who examined economic growth from an endogenous perspective, which considered the role innovation policies, resources and incentives, along with investment in human capital, can play in fostering progress. From this new perspective, the emphasis was on governments to support innovation through such interventions for long-term macroeconomic growth.

This revised perspective on economic growth led researchers to study the ways in which economies endogenously transform, ultimately leading to the development of systems of innovation theory. It is this theory that forms the basis for the research framework of the paper. In the first instance, the work of Freeman (1987), Lundvall (1992) and Nelson (1993) shaped the concept of national systems of innovation (NSI). The concept aimed to address "the contrast between the general consensus that technical change is the most important source of dynamism in capitalist economies and its relative neglect in most mainstream economics literature" (Freeman, 1998). It has since proven to be well positioned to "explain how innovation and learning processes may be stimulated in such a way that they contribute to economic growth" (Lundvall, 2007), and has provided an accessible tool for policymakers.

Each of these authors offer a different perspective on the concept. Freeman's understanding emerged from investigation of Japan's innovation performance and was described as "the

network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies” (Freeman, 1987). Lundvall’s perspective focussed on the processes of learning and knowledge creation, the type of innovation (i.e. radical or incremental), the role of non-market institutions and, as something of a precursor to the conception of regional systems of innovation, the importance of geographical proximity (Lundvall, 1992). The role of the state is key, with Lundvall distinguishing between the governing institutions and the firms and consumers (i.e. actors) within the system. Nelson (1993) describes an NSI as “a set of institutions whose interactions determine the innovation performance of national firms” and is interested in analysing these institutions (particularly universities) and the ways in which the system is organised.

A system is comprised of actors (public and private sector, such as firms, universities/public research institutes and relevant intermediaries), interactions (flows of knowledge between these actors) and institutions. Whilst varying definitions exist in the literature for the term ‘institutions’, it is used here as described by Edquist (2005) as “the rules of the game”: i.e. the customs, norms, laws, regulations and policies that govern the interactions between actors. An NSI holds the government at the centre of the system, in a coordinating role, responsible for establishing the institutions therein. Whereas previous approaches had focussed exclusively on the market, the systems of innovation approach includes a much wider range of organisations. Institutions are often designed to enhance the system’s coordination and encourage cooperation between the actors in knowledge diffusion activities and developing cognitive capacity (Soete et al., 2010). The framework has a particular attractiveness to policymakers, highlighting the need for complementary policies and addressing weaknesses in the system against a national context (ibid).

It is important to note that a distinction can be made between ‘narrow’ and ‘broad’ perspectives on the theory. The core elements (actors, institutions and intermediaries) are present in both definitions. The narrow definition of an NSI includes only the institutions and policies directly related to scientific and technological innovation, whereas the broad definition also considers the social, cultural and political environment of the country, including the national financial system, monetary policies, labour markets and regulatory policies (Feinson, 2003). This is a significant distinction to make, as this study adopts a broad perspective, and considers the countries’ political landscape (and political history) and socioeconomic conditions when drawing conclusions on the influential factors behind policy decisions. Lastres et al. (2003) stressed the importance of taking macroeconomic, political, institutional and financial factors into account when assessing the innovation systems of less developed countries. There are often significant constraints to innovation in those countries, such as hyperinflation, high

external debt and high interest rates. Similarly, macroeconomic stability and a supportive regulatory environment have been shown to be important to technological progress in a study by the OECD (1999).

More recently, and of equal importance here, is the concept of sectoral systems of innovation (SSI), led by the work of Franco Malerba (2003; 2004). Whereas the boundaries of an NSI are delineated geographically, an SSI concerns a specific industrial segment. SSIs are “the specific clusters of the firms, technologies and industries involved in the generation and diffusion of new technologies and in the knowledge flows that take place amongst them” (Breschi and Malerba, 1997). Each SSI will have a set of specific knowledge bases, inputs, technologies and learning processes (Malerba, 2004). The concept provides an analytical framework for determining how effectively a system supports innovation in a particular sector (Malerba, 2004; cited in Carayannis, 2015).

As with an NSI, an SSI is comprised of actors, institutions and interactions. Here, the actors are primarily private firms but the role of other actors (e.g. customers, scientists/researchers, entrepreneurs, universities/research institutes and industry intermediaries) should also be considered. The system’s success hinges on the interactions between these actors: “innovation and production are considered to be processes that involve systematic interactions among a wide variety of actors for the generation and exchange of knowledge relevant to innovation and its commercialisation” (Malerba, 2004). Malerba places an emphasis on the knowledge, learning processes and technologies created and diffused within the system. The elements and boundaries of a system have been seen to co-evolve over time, creating and responding to new actors and technologies, and reacting to changes in customer needs and the sector’s knowledge base (Malerba, 2003).

Most studies in the SSI literature are focussed on developed nations. However, as noted by Malerba and Mani (2009), there is a growing interest in studying developing countries from this perspective. This is due, the authors believe, to the increasing importance of innovation in these countries, the technology-driven transformation of traditional sectors, and the creation of new national sectors. The text examines a number of SSIs in developing nations, including Brazil (Marques and Oliveira, 2009; Perini, 2009; Toivanen and Lima-Toivanen, 2009), and amongst the authors’ conclusions is the observation that government has the potential to act as either a facilitator or an obstacle in the development of an SSI.

The relationship between two systems of innovation

There are clearly different approaches from which systemic innovative behaviour can be observed and interpreted. As noted by Meuer et al. (2015), these approaches infer the co-

existence of systems of innovation across multiple levels of analysis. For example, co-existence of regional and national systems can be observed in the work of Asheim and Coenen (2005), who, in outlining a typology of regional systems of innovation, describe ‘regionalised national innovation systems’, whereby innovation activities primarily occur in cooperation with national and international actors outside of the region. This can be observed elsewhere in Cooke et al. (1997) discuss innovation systems within regions with national claims, such as Scotland and Wales in the UK, due to their devolved economic powers. Similarly, the SSI literature has acknowledged the interaction of sectoral actors within specific territories. Industry clusters are one example of specialised sectoral knowledge bases agglomerating to certain locations. Researchers have elsewhere characterised SSIs by the interactions between actors and institutions at various geographical levels (e.g. Carlsson et al., 2002; Malerba, 2004). Also, the innovative activities of a single multinational enterprise (MNE) will often traverse different national, regional and sectoral systems. This body of research suggests that a relationship does indeed exist between spatial and sectoral systems of innovation.

Whilst researchers have suggested the co-existence of different systems of innovation (Howells, 2005; Lundvall, 1992), the dynamic between these systems has received little attention (Meuer et al., 2015). Markard and Truffer (2008) offer a diagram of the relationship between national, sectoral and technological systems, which is simplified below to include only NSI and SSI components in reflection of the remit of the paper (refer Figure 2). Here, a certain SSI will traverse several national systems and, similarly, a given NSI will have strengths in many different industrial sectors. Despite offering this useful graphical representation of the relationships between innovation systems, the authors do not go as far as to explore the intersection between these systems. Figure 2 will later form the basis for the study’s research framework.

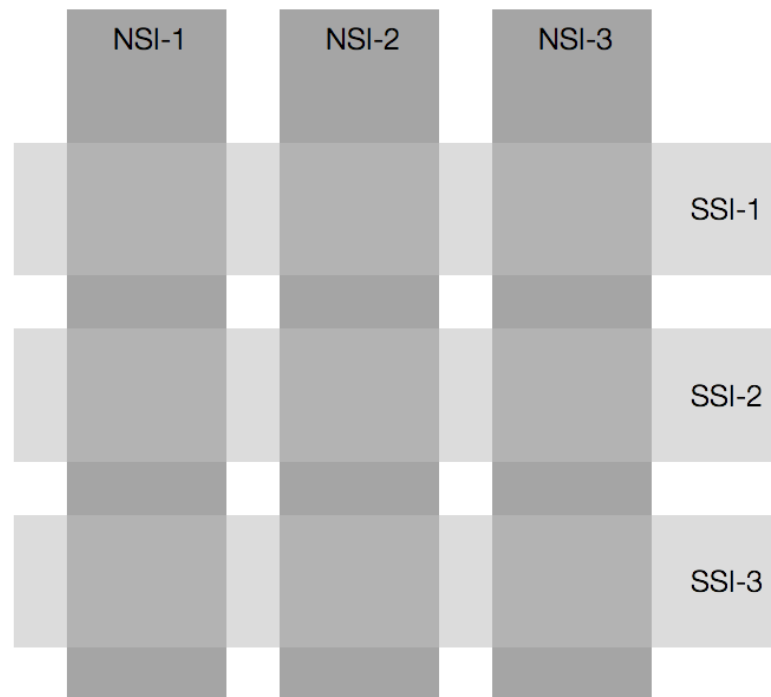


Figure 2: Potential relationship between national and sectoral systems of innovation (adapted from Markard and Truffer, 2008)

Institutions and policy in systems of innovation

Institutions play an important role in shaping a system of innovation and the behaviour of the actors therein. Institutions at different levels of analysis impact upon one another (e.g. national institutions will favour those sectors that best fit the features of the NSI; Malerba, 2003). At the same time, many countries support certain sectors over others with regards to resources in the pursuit of excellence in those sectors.

Edquist and Johnson (1997) classify institutions across four dimensions: formal (e.g. laws, regulations) vs. informal (e.g. customs, traditions, norms); basic (e.g. basic instructions around property rights, conflict management) vs. supportive (e.g. concerning the implementation of these instructions); hard (binding and regulated) vs. soft (i.e. more suggestive); and consciously vs. unconsciously designed (Soete et al., 2010). Whilst the term ‘institution’ clearly extends beyond laws and regulations, it is the formalised, hard and consciously designed governmental policies that are the focus of this paper.

In both case studies, policymaking is directed at systems of innovation transformation, which is a complicated process. It requires a changing portfolio of policies and supporting mechanisms to encourage coordination between the new elements of the system (Teubal, 2002). This perhaps explains why policy imitation is such a common course of action for developing countries, which generally have less knowledge and fewer capabilities around system

transformation. This imitation effect has been previously observed in national technology programmes in the fields of information and communication technologies, materials science and biotechnology (Edquist, 2001).

The discussion of policymaking in systems of innovation is also informed by the literature around national and sectoral regulation. At the national level, and under the framework of Varieties of Capitalism, sectoral specialisation is observed to emerge from national institutions (Hall and Soskice, 2001). This is similar to the finding of Malerba (2003) regarding governments favouring industries that align with a country's NSI. However, such a notion relies on the assumption that coherence between sectoral and national levels of policy is assured (Schröder and Voelzkow, 2016). Kitschelt (1991) commented that this adopts a view of homogeneity in national governmental regulation, thereby ignoring "considerable policy variance across industrial sectors within each country". The author suggests an alternative perspective, whereby sectoral and national institutions emerge from sectoral needs. This notion is supported elsewhere by Hollingsworth et al. (1994): "modes of economic governance may differ not only by countries – reflecting different institutional legacies and distributions of national political power – but also by sectors, in accordance with specific economic and technological conditions". Such a perspective acknowledges that national policy intervention influences sectors, and vice-versa (Schröder and Voelzkow, 2016).

Several researchers have examined the dynamic between institutions at both national and sectoral levels of analysis in emphasising the importance of institutional complementarities. This complementarity is described by Amable (2003) as being present "when the existence or the particular form taken by an institution in one area reinforces the presence, functioning, or efficiency of another institution in another area". Freeman (2002) highlights the need for complementarity between national and sub-national (including sectoral) institutions for the development of systems of innovation. Two contributions to Malerba's (2004) seminal text on the SSI framework (Casper and Soskice, 2004; Coriat and Weinstein, 2004) similarly assessed this complementarity as the main factor behind innovation performance and socio-technical change (Borrás and Edler, 2014).

Ultimately, the role of institutions is to encourage and/or incentivise desirable behaviours and actions from the actors of a system (Edquist, 1997). The Norwegian example demonstrates how sectoral policy interventions established patterns of reciprocal learning between domestic and foreign actors (i.e. desirable behaviour). This example also illustrates another of Edquist's (1997) core dimensions of systems of innovation: innovation is a product of interactive learning between actors in the system (i.e. it does not generally emerge from firms in isolation). The Norwegian intervention resulted in the creation of industrial technologies and practices that

have come to define the ways in which offshore oil exploration and production is undertaken. Given the size of the pre-salt discovery, the potential is there for the Brazilian government to encourage similar behaviours through sectoral policies in pursuit of comparable innovation success.

However, the ability of a developing country to innovate in light of a natural resource discovery will largely depend upon its ability to best take advantage of global knowledge flows (Feinson, 2003). The thoughts of Juma et al. (2001) encapsulate the policy challenge for the Brazilian government:

“Developing countries will have to move from natural resource extraction economies to knowledge-based ventures that add value to these resources. All these changes require a shift in public policy at the national and global level. Domestic innovation will not be possible without access to international markets; access to international markets will not be possible without domestic technological innovation”.

The considerations of the authors, along with those concerning institutional complementarities, are addressed in the conceptual framework that follows.

Conceptual Framework

The literature review has outlined the co-existence of national and sectoral systems of innovation, and the need for research into the relationship between these two systems. The literature also acknowledges the differing drivers and policy goals of each system (e.g. Hollingsworth et al., 1994; Kitschelt, 1991). An intersection exists between a particular national border and a specific industrial sector, which is embedded in the global context. Policy interventions at the national level influence sectors, and sectoral interventions affect national economies (Schröder and Voelzkow, 2016). Institutions can reinforce and support one another, although they may equally contradict and conflict with one another (Edquist, 2001). A shortcoming of the literature is the assumption that institutional complementarities will occur effortlessly between systems of innovation. Whilst these institutions can take several different forms, the focus of the paper is governmental policy.

Governmental intervention emerges from the ‘policy demands’ of an innovation system (Lundvall and Borrás, 1997): those being the collective but diverse needs and interests of the system’s actors. SSI policy demands concern the pursuit of innovation to address the technological challenges and opportunities of the sector within the context of a particular country. This will include enhancing the domestic innovation capacity in the sector and – in many cases, and particularly in developing countries – the attraction of foreign R&D

investment (Fu et al., 2011). NSI policy demands concern the broader desire to enhance the *country's* innovative capacity, as well as goals for socioeconomic betterment. In summary, the two systems may favour different innovation pathways.

The paper explores how a conflict between the policy demands of national and sectoral systems of innovation can hinder the innovative performance and socio-technical development of those systems. The first of three propositions to be investigated is thus:

- Conflicts can arise between the policy demands of national and sectoral systems of innovation. If not resolved, these can negatively affect the innovation performance of one or both of these systems.

This is not to say that the co-existence of these systems in a harmonious equilibrium is realistic. These are dynamic systems, whose components (i.e. actors, institutions, interactions, knowledge and technology bases, etc.) are constantly changing. Varying states of disharmony between systems is inevitable. Policymakers should, however, identify, understand and account for these conflicting policy demands, so as to minimise the negative effects.

The model of converging innovation systems offered by Markard and Truffer (2008) is adapted in Figure 3 to reflect the co-existence of the case study innovation systems. The framework sketches the relationship between the policy demands of these systems and underlying macroeconomic and socio-political conditions. The latter are pivotal to a further proposition of the paper (discussed momentarily), and were identified in the literature review as: important factors in assessing innovation systems (Lastres et al., 2003); sources of policy variance (Hollingsworth et al., 1994); and significant to innovation performance (OECD, 1999).

Under this framework, the global oil and gas sector traverses the national systems of innovation of Norway and Brazil. These case studies concern different points in time, both of which regard the years immediately following a large natural resources discovery. At the point of intersection between two systems lies the state and its policy portfolio, the effectiveness of which in reconciling the policy demands of the relevant systems will determine the extent to which a conflict exists.

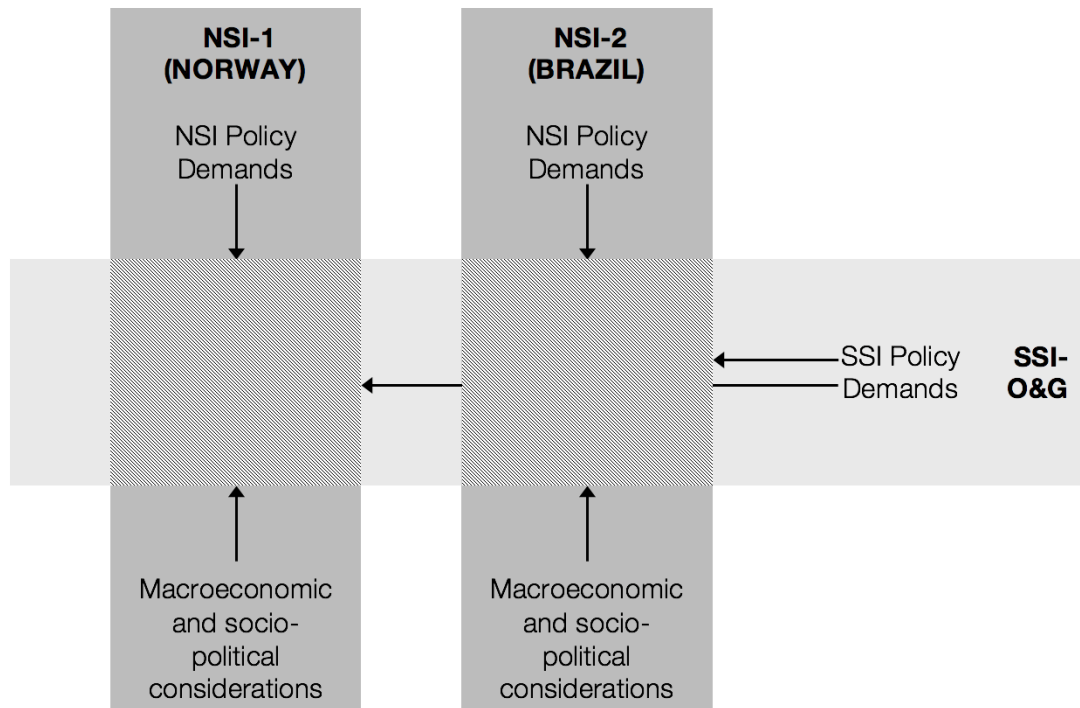


Figure 3: Conceptual framework

In discussing national systems of innovation, Lundvall and Borrás (1997) stated that:

“The capacity of policymakers and institutions to understand, adapt and anticipate policy demands by designing optimal policy instruments is crucial for the [innovation] system’s performance”.

This notion is extended here. The national government plays a pivotal role in the NSI-SSI intersection as an actor that traverses both systems and has a responsibility to manage these diverse policy demands. The literature emphasises the importance of effective policy to the innovation performance of countries and sectors and emphasises the significance of this role. However, policymakers cannot assume coherence between national and sectoral levels of policy (Schröder and Voelzkow, 2016). Therefore, this role encompasses not only policy setting but also, in reference to Lundvall and Borrás (1997), exhibiting the capacity to understand, adapt and anticipate *conflicting* policy demands by designing optimal policy instruments. The second proposition is thus:

- The reconciliation of national and sectoral innovation systems’ policy demands requires the implementation of well-considered policy interventions.

The process of reconciling policy demands is an iterative one for policymakers. It requires the frequent identification of conflicts between policies and addressing them through

amended/further policy interventions. Such a process is described in the literature as ‘policy learning’ (refer Mytelka and Smith, 2002). “The multi-layered, multi-dimensional and multi-targeted nature of policy and policy-making necessitates complex and effective policy learning mechanisms that allow policy-makers to both monitor and evaluate policies, and to anticipate and effectively react in advance to future changes” (Metcalf et al., 2002). It involves the creation and absorption of new knowledge by policymakers, the disregarding of past routines when necessary, and the capacity with which to identify new policy opportunities as they arise (Koschatzky and Stahlecker, 2009). The NSI-SSI interface will continually change and the effective management of the policy demands of the systems will require policymakers to both identify and anticipate these changes, particularly where these may reinforce conflicts or contradictions. The concept of policy learning aligns with systems of innovation theory, which emphasises learning as a cumulative process for system development (Lundvall, 1992).

The role of the state does, of course, extend beyond policy to include financial support and other interventions such as training and education, and, as such, an examination of the NSI-SSI intersection would be possible through the study of these other interventions. However, the literature emphasises the pivotal role of policy in shaping systems of innovation (e.g. Freeman, 1987; Edquist, 1997; 2004; Teubal, 2002) – a further advantage of examining which is the ease of accessing policy information – and it is therefore the focus of the paper.

Conversely, it would be possible to undertake an evaluation of policy complementarity without utilising the systems of innovation approach. Recently, researchers have questioned the delimiting nature of innovation systems frameworks (Coombs, 2001; Sharif, 2006) in light of increasing internationalisation of governance, firms and markets (Meuer et al., 2015). Models have since emerged that define innovation systems irrespective of their spatial, or sectoral boundaries (e.g. Meuer et al., 2015; Whitley, 2007). However, the use of national and sectoral systems of innovation theory is beneficial to the study as it provides a framework for comparing the idiosyncrasies of each system, which, beyond the policies themselves, also captures the many diverse actors and the interactions between them. This allows for weaknesses in the system to be identified that may not otherwise be evident. Similarly, it encourages socio-political and macroeconomic factors to also be considered, which is pivotal to the third proposition of this study.

The potential for socio-political and macroeconomic factors to influence the innovation pathway adopted by a country in light of a technology opportunity has not previously been explored explicitly in respect to co-existing systems of innovation. However, researchers have arrived at supporting conclusions in the past. Developing countries often favour protectionist policies in light of unemployment and recession – which commonly include trade and

investment policies – to safeguard domestic sectors from foreign competition (De Mello Jr., 1997). Brazil has a long history of such policies, which is discussed in the subsequent section of this paper. However, protectionist policies often lead to significant shortcomings in innovative capacity and international competitiveness of domestic companies (Reinhardt and Peres, 2000; Roett, 1997). To frame it another way, they address the macroeconomic conditions of the country but often fail to satisfy the policy demands of the SSI.

There are significant constraints to innovation evident in developing countries that emerge from the less favourable macroeconomic and socio-political conditions (Lastres et al., 2003). Developing countries have a lower R&D expenditure, a lesser reliance on localised knowledge institutions, and a greater dependence on foreign technology than their developed country counterparts (Arocena and Sutz, 2000). Conversely, a stable macroeconomic environment and supportive regulatory environment is imperative to technological progress (OECD, 1999), whereas developing countries are often ruled by fragile political and institutional systems (OECD, 2010). The innovation systems of developing countries are qualitatively different, described by Melo (2001) as “handicapped systems”, due to the entrenched technological and productivity gap they must overcome in order to ‘catch-up’ to advanced economies.

This paper draws from only one developing country case study, and thus broad generalisations about co-existing innovation systems in developing countries will not be made. However, in light of the preceding discussion, and Brazil’s past and current experiences of protectionism (discussed subsequently), the following third proposition is offered:

- Following the identification of a large-scale innovation opportunity, Brazil has a tendency to neglect the policy demands of the sector, so as to pursue the policy demands of the NSI and goals for the improvement of the country’s socioeconomic conditions.

The two cases of Brazil and Norway are ideal for the evaluation of the NSI-SSI intersection. The literature acknowledges that governmental intervention will be increased during times of sectoral transformation (Edquist et al., 2004; Teubal, 2002), which is evident in both case studies, as driven by large natural resource discoveries. The government has long played an active role in Brazil’s oil industry, even following privatisation of the national oil champion, Petrobras. Similarly, the Norwegian government quickly took a leadership role in steering growth in the national oil industry during the North Sea development (also discussed later in this paper). The national oil champions of both countries are still majority-owned by the respective national governments. As such, government in each case study holds an active role in *both* systems of innovation. This role is dual-focussed; divided between responsibilities to

pursue socioeconomic and human capital gains for the national population, whilst also driving innovation and industrial growth in domestic sectors. Where this dual role of government is effective, the systems' different and often contradictory policy demands will be reconciled; where they are not, a conflict may arise.

Historical Considerations

The sectoral policy decisions recently made by the Brazilian government are certainly informed by their past experience with industrial policy. One such policy approach is Import Substitution Industrialisation (ISI): the fostering of domestic production of previously-imported manufactured goods. It was adopted across the developing world following the end of the Second World War, with particularly strong commitment from many Latin American governments (including Brazil) in the 1950s and 1960s in pursuit of socioeconomic development (Baer, 1972). The policies enacted in Brazil were developed by Latin American economists Raúl Prebisch and Celso Furtado, who were leading researchers of Dependency Theory, which describes the relationship between developed and developing nations: the former creates and sustains a state of dependence from the latter in order to exploit that country's natural resources and cheap labour. ISI is grounded in the proposition that developing nations should look to reduce this dependency through policy intervention.

In Brazil, the ISI approach was successful in increasing the production of industrial goods and promoting diversification into new sectors at a time when industry in the country was focussed primarily on agriculture and mining. The interventions included the protection of domestic markets through the control of imports, attracting foreign direct investment through various incentives, establishing national champions in key industries (which led to the creation of Petrobras), founding a national development bank (BNDES), and the promotion of selected sectors (Baer, 2001; Baer and Paiva, 1997; Orenstein and Sochaczewski, 1990).

This drove two periods of exceptional growth in Brazil: 1956-61, as guided by President Juscelino Kubitschek under the slogan 'fifty years of progress in five', followed by the 'Brazilian Miracle' in the late 1960s to mid-1970s, both of which saw growth rates of around nine per cent, pushing the economy from 30th to 10th place in the world. Most impressive of all, between 1968 and 1980, the country's ISI strategy (coupled with export incentives) led to an increase from 20 per cent to 57 per cent in the share of industrial goods in domestic exports (Cavalcanti, 1996). It is still one of the strongest examples of a developing nation becoming an industrialised world power within the span of two decades. The success today of Embraer – Brazil's national aerospace champion, which, like Petrobras, was created by the government

in the 1960s as part of the ISI strategy – can only be understood with consideration of the role this strategy played in nurturing the company’s growth in its infancy.

The periods of rapid growth did, however, lead the country into huge levels of foreign debt (which increased from US\$6.4 billion in 1963 to nearly US\$54 billion in 1980; Buechler, 2014). The ISI approach led to sectors being plagued with inefficiencies, a diminished innovative capacity and a lack of international competitiveness (Reinhardt and Peres, 2000; Roett, 1997): something that endures in Brazilian petroleum to this day. Following an oil shock in 1979 that saw the price of imported oil nearly double (at a time when Brazil was a large net importer), growth stagnated in the 1980s, which became known as the ‘lost decade’ in Latin America. Doubts concerning Brazil’s ability to pay its debts halted further lending. Nevertheless, the government persisted with an ISI approach until the late 1980s. The following decade brought the introduction of a New Economic Model (NEM) and, with it, the privatisation of domestic industry leaders, including Petrobras and Embraer.

In the last few years, Brazil has seen the reinstatement of protectionist ISI policies: some have even dubbed this current period, particularly with regards to the intervention in the petroleum industry, ‘ISI 2.0’ (Troyjo, 2012). Brazil’s protectionist approach today, embodied in its current sectoral policies, legislation and contractual mechanisms, is indicative of the government’s renewed hope in such an approach. The discussion of the empirical case will highlight how a protectionist approach such as this satisfies the policy demands of the NSI but conflicts with those of the SSI, and looks destined to repeat many of the failings of ‘ISI 1.0’ (i.e. diminished innovative capacity and international competitiveness of the industry beyond the national champion).

The Norwegian example

The development of the Norwegian petroleum sector is discussed here in order to provide a basis of comparison with the Brazilian empirical case study. The Norwegian case is a leading example of how to successfully build an innovative domestic supply sector following a large natural resource discovery. As such, Brazil can learn much from Norway’s experience, given the considerable similarities to the pre-salt scenario. These similarities, and the notable differences, will be discussed in the subsequent sections under the context of the Brazilian case study.

Today, Norway is the second-largest exporter of gas and the fifth-largest exporter of oil in the world. The national oil company, Statoil (which, like Petrobras, is majority-owned by the national government), is a global industry leader and employs over 21,000 people in 36

countries (Statoil, 2015). Statoil is also the second largest operator in Brazilian petroleum after Petrobras. Beyond Statoil, the Norwegian oil industry has an abundance of specialised suppliers, many operating globally, and Norway is an established world-leader in subsea petroleum technologies. The Norwegian example is described by Hatakenaka et al. (2006) as “a textbook case of how to build local innovative capabilities”.

Just over forty years ago, Norway did not have much to speak of in terms of a petroleum industry, and it was foreign oil firms that discovered significant offshore oil reserves in the North Sea in the late 1960s. Upon their discovery, the national government began to carefully consider the role such reserves could play to the future of its national economy (Aamo, 1975; cited in Earney, 1992). Statoil was established soon after, along with a series of policies aimed at ensuring that the newfound reserves were utilised to provide for the country: a foundation upon which a set of new companies and technologies could be established and marketed around the world. The policy’s success was swift and within a decade Norway had established itself as a significant force in global petroleum. Engen (2009) notes Norway’s “remarkable achievement” in accomplishing the dual (and not necessarily compatible) goals of developing new technologies to address one of the industry’s greatest technical challenges, while simultaneously supporting the participation (and later global competitiveness) of domestic suppliers.

As Earney (1982) observed at the time, while the prospects of foreign markets in the future appeared very promising, the Norwegian government proceeded with caution. The author cites a parliamentary white paper that outlines the intention of the Norwegian government to oversee controlled, measured development of the reserves:

“The central objective of the government’s oil policy is that the administration and exploitation of these resources should take place in a way which will give the best result for Norway from a national economic point of view, and that the whole Norwegian society should benefit” (Ministry of Petroleum and Energy, 1980).

The Norwegian government sought the participation of domestic suppliers wherever possible. In 1978, cooperation between operators and domestic suppliers was stipulated in oil field concession contracts with the introduction of so-called ‘technology agreements’ (refer Fagerberg et al., 2009). These agreements were indicative of the government’s commitment to have foreign firms contribute to national technological and industrial development through collaboration with domestic firms. These agreements had a positive impact in establishing relationships between foreign MNEs and domestic firms and led to the transfer of the latest technologies, knowledge and practices in oil and gas to Norwegian petroleum companies

(Vorobyov, 2012). Vorobyov (2012) illustrates the effect of the agreements with case studies of two Shell projects in the 1980s – ‘Troll Phase 1’ and ‘Draugen’ – where 73% and 80% respectively of the total project expenditure was allocated to Norwegian contractors. The enactment of these technology agreements was pivotal to the development of the country’s domestic oil industry.

This was augmented by the country’s stance on local content (the procurement of domestic goods and services). Operators with a high degree of local content were given principal standing in the bidding process. The sophistication of the work undertaken by domestic firms increased considerably, with traditional industries, such as shipyards, transforming into suppliers of offshore petroleum technologies (Engen, 2009). This was successful in increasing the domestic supply of petroleum services from 28 per cent in 1975 to 62 per cent in 1978, with these high levels of local content enduring to this day (Thurber and Istadd, 2010).

Even in this early stage of development, knowledge spillovers between MNEs and domestic suppliers were evident (Sæther et al., 2011). The involvement of foreign firms was controlled: utilising their expertise and experience when necessary, whilst also ensuring that opportunities were created for the domestic supply sector. This approach ultimately proved to be a significant advantage to the competitiveness of domestic suppliers when they would later expand into export markets (Cappelen and Mjøset, 2013). It also echoes the sentiments of Juma et al. (2001), who attested that governmental policy intervention should seek a balance between supporting access to global knowledge bases and championing domestic innovative capacity.

The policy intervention of the Norwegian government in this early stage, termed by Engen (2009) as the ‘consolidation’ phase, produced both benefits and shortcomings for the industry. Increased national income and employment for the country was balanced against greater bureaucracy and costs for operators. Statoil continued to develop into an integrated petroleum company, and two Norwegian suppliers, Aker and Kværner (who would later merge and are now known as Aker Solutions – one of the world’s leading oil companies), established themselves as main contractors (ibid). Whilst industry prospered, there was a notable lack of participation from Norwegian universities and public research institutes in R&D activities. This was addressed in 1979 through the enactment of the ‘Goodwill Agreements’: declarations of intent from operators to cooperate with research organisations in their innovation efforts. These proved instrumental in forming a national research capacity in petroleum studies (Sæther et al., 2011) and long-lasting collaborations between research and industry actors. The Research Council of Norway evaluated these Goodwill Agreements under the guiding principle of “quantity does not mean quality” (Vorobyov, 2012): measuring a foreign firm’s contribution

to building domestic innovative capacity, as opposed to simply the level of investment committed.

This approach endured for over twenty years until the 1990s, during which time one of the world's leading petroleum industries was formed. This was built upon a collaborative approach by the actors in the SSI, as underlined by the policy approach of the government. Raising costs and restraining growth in the industry in the short-term, it has since proven pivotal to the long-term gains the industry has enjoyed. Participation of domestic firms steadily increased, as did their innovative capacity and international competitiveness. This would eventually lead many of these firms to venture successfully into export markets, with a particular expertise emerging in subsea technologies. Further to this, Norway successfully avoided the resource curse (whereby an abundance of natural resources leads to a decline in the growth of other economic sectors). The petroleum industry has both co-evolved with other national industries (Sæther et al., 2011) and provided substantial spillovers (knowledge, productivity, human capital and technology) into non-oil sectors (Bjørnland and Thorsrud 2014; Cappelen and Mjøset, 2013), thereby bringing further economic development and technology opportunities to the country.

There are several important observations from this case study that are worth emphasising before discussing the Brazilian case. First is the Norwegian government's successful reconciliation of policy demands, both within and across systems of innovation. Within the SSI, they were able to balance access to global knowledge bases with fostering growth, competitiveness and innovation in the domestic supply sector. These two feats were not achieved in isolation: policy was designed to ensure that foreign knowledge bases were utilised in the development of domestic industry. The policy demands were equally reconciled across the NSI-SSI intersection to ensure that the North Sea development provided similar opportunities (via spillovers) for many other economic sectors, advanced the national university system, and improved the country's broader socioeconomic conditions.

Secondly, the Norwegian government demonstrated a strong ability to identify overlooked policy demands and address them (i.e. policy learning). The opportunity to increase the involvement of national universities in the North Sea development was recognised and thus a policy instrument (the Goodwill Agreements) was designed and implemented to address this. Finally, it is important to note that throughout the sector's development, Norway's political environment was stable and the macroeconomic conditions were extremely favourable. This observation will be returned to later in the paper.

Brazilian petroleum's sectoral system of innovation and policy landscape

An analysis of the recent governmental policy interventions in Brazil's petroleum sector follows, which is drawn from a mix of bibliographical research, analysis of secondary data and field research. The latter was collected over two month-long visits to four cities in Brazil (in April 2014 and May 2015) and consisted of forty-five in-depth interviews with key actors in the sector. Interview subjects included MNEs, small domestic firms, academic experts, government agencies, non-government industry organisations and science park management groups. MNEs (from whom R&D/technology managers were interviewed) were selected based on their significant involvement in the Brazilian petroleum industry, with a particular focus on those residing in the Federal University of Rio de Janeiro's (UFRJ) science park. The park has recently emerged as a leading industry cluster in the country. Similarly, many of the small firms were identified due to being located in university science parks and business incubators, which are a plentiful source of ambitious, technology-driven firms.

The research is part of a broader study also examining the role universities and MNEs are playing in shaping the national and sectoral innovation systems. Interviews were semi-structured and addressed the dynamics of the systems of innovation (including how these have changed since the pre-salt discovery), the role that policy has played in shaping these changes, and the opportunities and challenges the system faces in the future. Whilst, for reasons of brevity, only a selected few interview subjects will be directly referenced in this paper, the key discussion points were spoken about at length with all interviewees, and the findings and conclusions herein were arrived at through an analysis of these discussions.

The Brazilian oil industry has enjoyed healthy growth over the last two decades. Oil production has increased by an average of 5% since 2000 (Rapoza, 2015). Most recently, and following the pre-salt discoveries, global exploration activities have increasingly been focussed on Brazil: in the last four years, over a third of the world's oil discoveries (and almost two-thirds of the world's deep-water discoveries) have been made in Brazil (ibid). During this time, the success rate of extraction in the pre-salt fields has been extraordinarily high: 90 per cent against a global industry average of between 20 and 25 per cent (Jimenez, 2013; de Oliveira et al., 2014). Since commencement of production in the pre-salt region, over 100 million barrels have been extracted. In April 2014, the fields were yielding over 400,000 barrels/day, which has steadily increased. Petrobras has set a target for pre-salt oil to account for over half of total production by 2018 (EIA, 2013). The industry is also of considerable importance to the national economy and accounts for 13 per cent of the country's gross domestic product (Petrobras, 2015a).

Petrobras, as the industry's national champion, is at the centre of all activities therein. The company produces 90 per cent of the country's petroleum (Horch, 2015). It is the country's largest firm, employing over 80,000 people (primarily in Brazil, although present in a further 16 countries), and in 2014 net revenue exceeded US\$90 billion (Petrobras, 2015b).

The company has a long-held commitment to R&D, which has understandably intensified since the pre-salt discoveries. In 2012, Petrobras had the second largest investment in R&D of the world's petroleum companies (US\$1.1 billion): an increase of 68% on the previous year (Petrobras, 2014a). The company remained ahead of other global oil firms, such as BP, Total and Exxon, by the same metric in 2013. Petrobras' R&D activities are headquartered in its Rio de Janeiro technology centre, CENPES, which received investments of US\$500 million in 2014 and in turn invested \$130 million in more than 100 Brazilian universities and research institutes (Petrobras, 2014b). CENPES is located close to UFRJ's science park, which has become the home of further technology centres established by eight leading global petroleum suppliers (including Halliburton, Siemens and Schlumberger).

Since the first pre-salt discovery was made in late 2007, many energy sector commentators have published on Brazil's perceived bright future in respect to both oil production and economic growth (for example EIA, 2014). At the time of the discovery, President Luiz Inácio Lula da Silva stated: "this wealth belongs to the whole Brazilian population. We know that pre-salt resources, if well administrated, can be a catalyst for great transformations in Brazil" (Wertheim, 2009). President Dilma Rousseff (at that time Secretary of State) claimed the pre-salt reserves were Brazil's "passport to the future".

Brazil's national government has since taken a more active role in the country's oil and gas SSI in terms of policies, funding opportunities and other incentives. The system's dynamics have changed considerably as a result, which has seen: a significant increase in R&D expenditure; the creation of new actors; the increased involvement of domestic firms in the supply chain; an enhanced role for universities and public research institutes; and the creation of technology centres in Brazil from some of the world's leading petroleum firms.

The government's approach to national petroleum reserves has moved from open to protectionist. Legislation has been introduced to ensure Petrobras will be the operator in all pre-salt oil fields (Federal Law No. 12.351/2010, Article 4). Brazilian oil field exploration and production contracts are increasingly moving away from a concession model (where control is handed to the concessionaire on a lease/licence basis in return for tax and royalties) to a production sharing model (which divides the produced oil between the winning bidder and the government). This change is a result of the government's objectives to (i) increase its interest

in the development of the pre-salt discoveries and (ii) maximise the revenue for the country thereafter. The use of production sharing contracts is becoming increasingly popular and will be the contractual model for the pre-salt oil fields (Federal Law No. 12.351/2010).

At this point, it is important to add clarification around the term ‘domestic supplier’ and, by extension, ‘domestic supply sector’. First, a distinction must be made between a domestic firm and a firm located in Brazil. Many of the industry’s leading multinational enterprises have a strong presence in Brazil (increasingly so since the pre-salt discovery), including regional offices, manufacturing plants and research and development facilities. However, a domestic supplier is defined here as a firm that is headquartered in Brazil and conducts its business primarily in Brazil. The definition of ‘domestic supply sector’ must be considered in light of a study by Hatakenaka et al. (2006) of the petroleum industries of Norway and Aberdeen, which found that three types of companies were required: oil exploration and production companies (referred to here as ‘operators’); large, global and integrated service providers (or ‘main contractors’) that offer products and services for exploration and production; and small, domestic and specialised product suppliers and service companies (‘the domestic supply sector’).

The main contractors tier is effectively a closed market, with customer-supplier relationships established over many years (even decades) in an industry where reliability is of absolute importance. However, the domestic supply sector, which refers to an ecology of suppliers beyond the main contractors tier, offers tremendous opportunities for the participation of Brazilian firms. The authors note that such firms “are often the pioneers in developing new technologies”. However, Neuhaus (2014) highlights the current lack of international competitiveness in the domestic supply sector of Brazilian petroleum: only 24 per cent of firms export; 80 per cent of which export less than 10 per cent of their total output. Figure 4 shows these tiers of companies, along with the other key actors in the system.

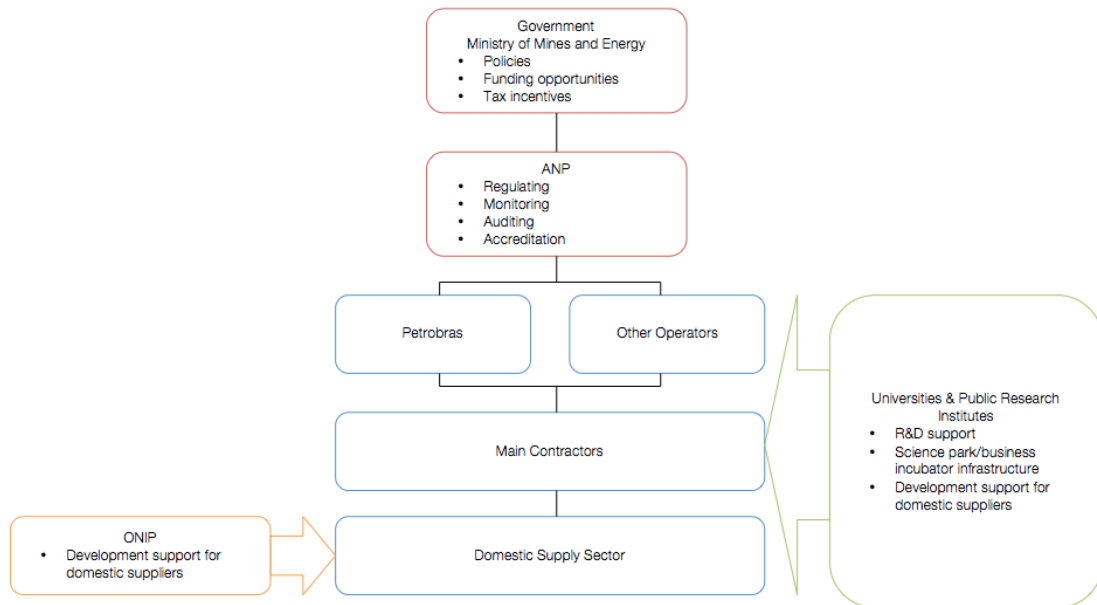


Figure 4: Brazilian Petroleum SSI

This paper focuses on the third tier of companies: specifically, the extent to which governmental policies effectively address the SSI’s growing need for an expansive and innovative domestic supply sector.

Two policies in particular are at the forefront of the push for increased innovation and domestic supplier participation in the industry. In 1997, the Brazilian government, in support of the privatisation of its national industries, brought about a constitutional amendment to end the nationalised monopoly of the petroleum industry (and Petrobras) after more than forty years. With this came the creation of the National Agency of Petroleum (ANP), a regulatory agency that was tasked with stimulating “research and adoption of new technologies for exploration, production, refining and processing” in the country (Federal Law No. 9.478/97; cited in Braga and Szklo, 2014). In 1998, a regulation was created by ANP (Federal Law No. 9.478/1997, Article 8) that stipulated the inclusion of a contractual obligation for operators in Brazil’s high-yielding oil fields. This obligation requires operators to invest 1 per cent of the gross revenue derived from exploration and production of these fields in the financing of R&D activities in Brazil. At least fifty per cent must be used to hire accredited Brazilian universities and public research institutes for R&D projects (although this extends to the construction of laboratories/workshops, purchase of equipment, instruments and materials, and personnel salaries). The other half of the funds can either be used internally (for R&D activities on the Brazilian premises of the operator) or to hire Brazilian companies for R&D projects. This policy will be referred to hereafter as the ‘1% Regulation’. Figure 5 shows the total funds raised through this regulation from all operators between 2000 and 2013.

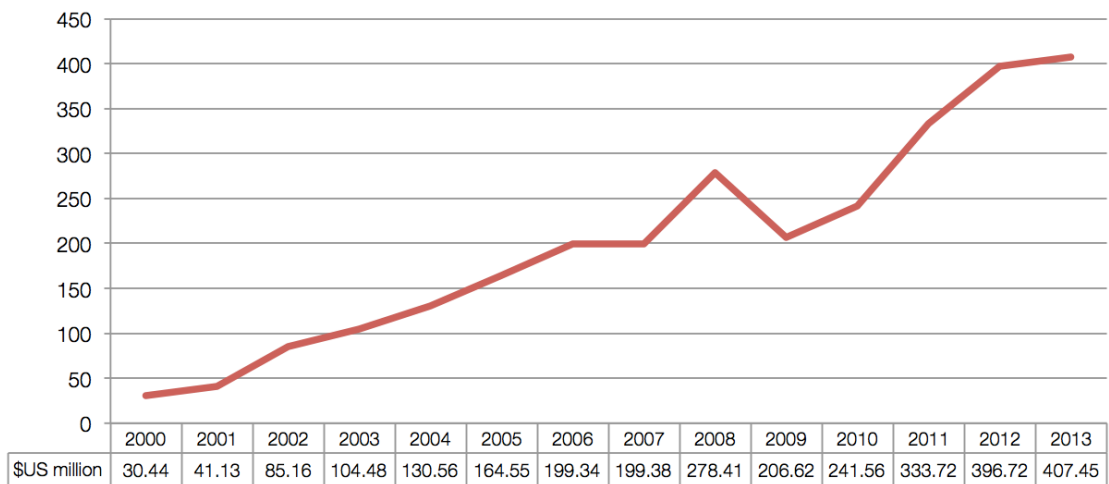


Figure 5: R&D investments from the 1% Regulation (2000-2013) in US\$ million (ANP, 2010; 2014b)

The 1% Regulation was discussed at length with Adilson de Oliveira – a Professor of Energy Policy at UFRJ with almost forty years of experience in the field. He stated that when the regulation was made, the government could not have envisaged the oil price would rise as high as it did and remain there for so long. A significant increase in production between 2005 and 2012 saw Petrobras’ R&D budget increase six fold over this time (confirmed by a technology manager at Petrobras in a subsequent interview). The company’s yearly R&D budget is US\$2 billion (as of mid-2015), at least half of which must be invested in universities and public research institutes. With production destined to increase as the pre-salt fields are developed (albeit under a currently diminished oil price), this fund is likely to grow much further in the next five to ten years. It is estimated that over the next ten years, US\$30 billion will be invested in R&D as a result of the 1% Regulation, compared to the US\$3 billion that has been invested through this policy between 1998 and 2014 (ANP, 2014a).

The second policy is local content. This is similar to the initiative from the Norwegian government, although in this case it is a contractual requirement that includes minimum targets that operators must meet for the procurement of domestic-supplied goods and services. These targets vary depending on the technical field of the product or service. Most recently, this has been set at 37 per cent in the exploration phase and 55 per cent in the development phase of oil field operations. ANP is responsible for monitoring the results of the policy. The Brazilian government has adopted the slogan “*tudo que pode ser feito no Brasil, tem que ser feito no Brasil*”: everything that can be done in Brazil, must be done in Brazil. This mirrors the mission of the Norwegian government during the early stages of the North Sea development. However, Geddes (2013) notes that local content programmes present both potential costs and benefits: costs with regards to market distortions, increased administrative expenditure and losses from business transactions that would not otherwise been made; benefits from greater domestic

employment and increased tax revenues from the higher participation of the domestic supply sector.

Brazil's local content policy was discussed at length with Samuel Tocalino, the founder of Adest: a micro-sized firm developing sand control screens (for the separation of sand at the seabed) for deep and ultra-deep water oil production. The firm was selected as a research subject due to its highly-innovative products, its partnership with a leading oil company and as a success story of the university business incubator model. Mr Tocalino stated that Adest had benefitted significantly from the local content requirements given the industry's resistance to change, aversion to risk and scepticism of innovations designed and produced in Brazil.

“The need for national content is [...] driving [growth]. If there was no need for national content, nobody would do anything in Brazil”.

Three other Brazilian firms – Ambidados, Polinova and Oil Finder, which were selected under the same rationale – also acknowledged the role local content had played in opening the market. Cíntia Soares is the Business Development Director of the latter, which specialises in remote technologies for the mapping of oil seepage on the seabed. Ms Soares emphasised the importance of local content and the 1% Regulation in promoting the use of domestic suppliers from operators and main contractors.

“[There are] people looking for innovation. It is more because of regulation and something that they have to comply with [rather] than because [...] they think innovation is going to bring a lot of value for [the] company. [...] Regulation was key for us. [...] If it were not for regulation they would not be thinking about innovation [in Brazil]. That is why government has a very important role”.

These policies (together with several sectoral development funds and human resources development programmes, which will not be discussed here for reasons of brevity) address the desire for Brazilian oil and gas, and the pre-salt reserves in particular, to provide for the future of the country.

The similarities between Brazil's petroleum SSI today and that of Norway forty years ago are many. Both national governments perceived a weakness in the technological capabilities and level of participation of domestic firms in the industry, thus adopting a protectionist approach and introducing sectoral interventions to address these shortcomings. In both cases, the pursuit of new oil reserves at unchallenged depths was perceived as an expensive and risky endeavour. However, this is where Brazil is at an advantage. During the 1960s and 1970s, the market share of the seven leading oil companies had decreased significantly. The challenge for the

Norwegian government lay in encouraging these companies to invest in what was something of an unknown venture (albeit one with potentially huge rewards). It was very successful in this, as Brazil has been. In Brazil, foreign investment has been incentivised by the government, although these high levels of investment can equally be attributed to the status of Petrobras: a company with a global reputation for world-leading expertise and technology in deep and ultra-deep water oil production. Norway had no such national champion at the time of the North Sea discoveries. The consensus of the industry's leading firms, many of whom were interviewed for this study, is that the pre-salt challenge, whilst tremendous in scale, is achievable and ultimately worthy of the investment required.

Analysis

While several interviewees identified the important role the government has played in promoting the domestic supply sector, the ways in which the two leading policies have been designed and applied raises some serious concerns, especially as the industry ventures further into the pre-salt development. These policies are discussed by their enactors in terms of a long-term perspective: transforming the industry into a highly-innovative driver of national growth, with a robust domestic supply sector and an array of world-leading technologies and competencies that can be sold around the world. This would reconcile the policy demands of both the NSI and SSI, as with Norway before. However, these aspirations have not been met, for several reasons.

First, the vast levels of investment made through the 1% Regulation do not involve the domestic supply sector, and typically benefit only two types of organisation: MNEs and public research institutes/universities. The 'internal 50%' of this requirement has seen many operators establish technology centres in Brazil. These firms do have the option to invest these funds in domestic suppliers. One such example of this is Adest, which benefitted from Statoil's 1% obligation. However, the occurrence of such an arrangement is very rare. Ribeiro and Furtado (2011) found that as of 2010, the three main contributors to this fund – Petrobras, Shell and Repsol – had not engaged in a single R&D project with Brazilian suppliers as a result of the regulation. In April 2014, Ramos de Souza, the then Director of ANP, confirmed the continuing rarity of cases in which the 1% obligation is used to support domestic firms: "it is possible to invest part of the [...] 50 per cent of the oil company in [...] supply companies. But the oil companies rarely do that".

The external 50% was originally conceived as a funding source for collaborative projects between universities and firms. However, given the tremendous funds available, the remit has been broadened so as to include the financing of infrastructure. For example, UFRJ's Institute

for Graduate Studies and Research in Engineering (COPPE) has received enormous levels of investment from Petrobras and now has truly world-leading laboratories in some fields. Petrobras is engaged with around 120 universities across Brazil (Olsen, 2013).

The suggestion was also made by several technology managers of MNEs that such infrastructure was underutilised, and that the 1% investment is being expended on non-R&D projects. For example:

“The 1% has been used with zero policy on looking for results. Universities do whatever they want, they [are] spoilt with the money, they [haven’t] delivered any results. They built labs. Now we have huge labs, marvellous labs that are being used for nothing. [...] Also, they use this 1% to support Brazilian students to study abroad on a government-sponsored programme. The students [...] go there, they study for some time, and they come back without any requirement to present results or maintain good grades while they are [abroad]. [...] A very expensive English course. Some other companies, such as Shell, use the 1% for different purposes. One project was looking at how whales behave on the coast. [...] Just giving away money and thinking technologies are going to develop is not working. The 1% is a great idea, a lot of money, but it should be used in a very different way” (Interviewee-A, MNE-1).

Brazil’s prioritisation of university-firm partnerships over inter-firm partnerships is equally at odds with the Norwegian example, and is proving detrimental to the development of the domestic industry. Under a very similar scenario, the Norwegian government formed collaborative relationships (some would say ‘forced marriages’) between small Norwegian companies and global petroleum MNEs through technology agreements. Domestic firms gained much more from this than financial investment: learning from the MNE’s expertise and utilising their technology base. This played a vital part in establishing the domestic supply sector and developing a raft of innovative new technologies in a remarkably short space of time. In Brazil, university-firm collaborations have been prioritised and the opportunity to use such vast funds to support innovation-driven collaborative partnerships between firms has been overlooked.

Several researchers have discussed the benefits of inter-firm relationships to domestic suppliers. For example, Humphrey and Schmitz (2004) found that such relationships in developing nations offer domestic firms an opportunity to access the technologies and best practices of MNEs, thereby enhancing their own capabilities. Moreira (2009) discusses how these relationships can close the technology gap between not just firms but also countries. Access to MNEs’ superior technology may in turn lead to improved productivity in the

domestic supply sector (Görg and Greenaway, 2004). Along with increases in productivity, Görg and Seric (2015) also present evidence of innovative capacity gains emerging from MNE-domestic supplier relationships. The authors also discuss the important role the state has in fostering such relationships through policy intervention. Battat et al. (1996) underline the need for such intervention, particularly in developing countries, given that domestic suppliers are often perceived by MNEs to be incapable of meeting requirements with regards to pricing, lead time, quality control and technology level. Thus, supporting MNE-domestic supplier relations should be a key objective for the Brazilian government in addressing the policy demands of the SSI.

The opportunities for the domestic supply sector were discussed with Carlos Camerini, who is a superintendent of ONIP (National Organisation of the Petroleum Industry), a private non-profit organisation with a mission of supporting domestic industry growth in Brazilian petroleum. In discussing the prior experiences of growth in Norwegian and UK petroleum, Mr Camerini affirmed that the lack of investment in domestic suppliers in Brazil was a serious concern:

“The biggest difference we have here for small companies, in comparison with the UK and Norway, [...] is here the government [does] not put money in small companies. [...] This is a very big problem. For instance, companies such as Ambidados or Oil Finder [...] will need to sell part of their company. Money is [the problem], not technology: they are very technological companies, they have very good expertise, they have been working with Petrobras. [...] Technology is not the big challenge for them. [For] the small companies, money is the most important [challenge]”.

The elevated status of universities over domestic firms can also be seen in the sectoral funding initiatives of the government. The recently discontinued CT-Petro fund, which for thirteen years was the leading source of public financial support for innovation in the industry, was focused on university-firm collaborations. The limitations of these funding initiatives are comprehensively discussed by Ribeiro and Furtado (2010). CT-Petro was managed by government agency FINEP (Financier of Studies and Projects), from which two project analysts were interviewed for the study. During the discussion, they addressed the investment in university-firm collaborations at the expense of the domestic supply sector.

“[There are] a lot of people who do not agree with how the 1% is invested. This has been the subject of public consultations. [...] However, everything still goes to the universities. Of course, we want this to go to the companies” (Thais Macieira, FINEP). “1% is a lot of money to be putting into universities” (Denise Cristiano Reigada,

FINEP). “Of course, universities need money for these state-of-the-art [facilities] and equipment but they already have a lot, they are ok now. Going forward, they could give this money to companies. [...] This is something that could help the sector” (Thais Macieira).

In acknowledgement of this shortcoming, ANP is currently in the process of enacting a revision to the 1% Regulation. The revision is aimed at reinforcing local content, with 10 per cent of the funds generated being directed to supporting Brazilian companies. This would leave an ‘internal 40%’, with 50 per cent remaining available for R&D projects with universities and research institutes. This has been under consideration for quite some time and was discussed with Mr de Souza of ANP in April 2014. A year later, several interviewees stated this was nearing finalisation. However, as of July 2016, it is still yet to be enacted.

The 1% Regulation is an innovative policy and has already led to the installation of world-leading facilities in Brazil’s universities and the Brazilian technology centres of foreign MNEs. Infrastructure such as this is undoubtedly important and valuable. However, the extent to which the policy is actually supporting Brazilian innovation, as was initially intended, is questionable. The external 50% continues to be earmarked for investment in universities for research, rather than innovation (as the technology manager of one operator attested). The technologies generated from the internal 50%, whilst developed in Brazil, are not Brazilian technologies (i.e. with the exception of Petrobras, they are being developed by foreign MNEs). There is also anecdotal evidence of operators and universities using the funds in ways beyond the remit of technology development. This missed opportunity will only be furthered in the future, with the 1% Regulation expected to raise a further US\$15 billion in the next ten years (ANP, 2014a) to be expended in universities and research institutes alone.

There is great potential in having these funds directed at inter-firm collaborations. Norway’s success in developing its supply sector was driven by well-considered policy interventions and achieved with only a fraction of the funding available through the 1% Regulation. ANP seems determined to go another way. The decision to invest so considerably in universities/research institutes, is indicative of a misguided protectionist approach adopted by the government since the pre-salt discovery. The NSI’s policy demands concerning the country’s broader innovative capacity and macroeconomic conditions (employment and oil revenues) have been prioritised. In doing so, this has failed to adequately address the SSI’s demands for sector-specific innovation and development of its domestic supply sector.

This can also be observed in the decision to sanction the use of production sharing contracts in the pre-salt (detailed at length in Braga and Szklo, 2014). Under such an arrangement, the

government profits directly from the extraction of oil, rather than from the licensing of production activities. Given this, the government has established a very ambitious production schedule, so as to pursue the pre-salt's potential as a huge source of national revenue. This conflicts with the SSI policy goal of domestic innovative capacity building, which requires a patient approach, as evidenced in the Norwegian example. The combination of high production targets and an underdeveloped domestic supply sector with insufficient technological prowess has led operators to demand that local content requirements be relaxed. This has been addressed recently in the Libra pre-salt field. The requirement for high-technology products/services in this field has been significantly reduced (e.g. submarine automation systems from 50 to 20 per cent), while basic engineering services have increased (from 50 to 90 per cent; Neuhaus, 2014), which allows the broader local content targets (37 per cent in the exploration phase and 55 per cent in the development phase) to still be met. This addresses nearer-term concerns of human capital and market growth without the supporting mechanisms to address the SSI's policy demands of enhancing the sector's innovative capacity. This is a worrying trend as the industry ventures further into the pre-salt development.

Local content also raises concerns with regards to the competitiveness of the supply sector, as highlighted in the preceding discussion of Brazil's history of ISI policies. To take the example of the country's shipbuilding industry (one of the most important sectors in petroleum), considerable growth is evident since the discovery of the pre-salt: from 2000 employees in the year 2000, to 7800 in 2010 (Folha de São Paulo, 2010). However, whilst employment has increased, the sector is laden with inefficiencies and is no closer to becoming competitive in the global marketplace. This was discussed with many of the interviewees, several of whom raised these concerns:

“The principle of the [local content] is good, trying to develop the country in parallel with oil production. [...] If you take away local content, you will have unemployment and [regression]. The question is, how to make these [suppliers] understand they need to be competitive? [...] Productivity in Brazil is low because of lack of management, not because of the skill of the people. [...] It makes no sense to have a big industry here if it is not competitive in maybe ten years. [...] An industry plan [is needed] for bringing the Brazilian industries to [...] international [competitiveness]” (Interviewee-B, MNE-2).

“With basic engineering at 90 per cent local content, [... the government] are looking to the market, [assessing] what can be produced in Brazil today [... and] defining local content based on that. However, where is the policy for high technology and improving local fabrication of this high technology in the next year? There should be a plan to

say now we have 10 per cent but in five years we will have 25 per cent. [...] What [is missing] is a long-term plan on the local content policy, which is always short-term” (Interviewee-C, MNE-2).

“Local content is a good policy for developing a country but it should be [focussed] on bringing technology in. [...] It should not be [...] permanent, [it should] be scaled back over time. [Otherwise], what is the purpose? It [should] develop local competencies. [...] If you look to shipbuilders in Brazil, they all rely on [local content] and do nothing to improve. [...] At present] it is a blank cheque for inefficiency” (Interviewee-A, MNE-1).

This is in stark contrast to the successful development of Norway’s supply sector, where local content was combined with initiatives to foster collaborative partnerships and promote the participation of domestic firms without protecting them. Local content in Brazil shows a much greater degree of protectionism, having moved away from supporting technology-focussed activities, as was originally envisaged for the policy, and creating severe inefficiencies. Whilst the government is following its slogan of ‘everything that can be done in Brazil, must be done in Brazil’, there is seemingly no drive to improve the scope, innovativeness or international competitiveness of these activities in the long-term.

By way of summarising the Brazilian case presented here and contrasting it with the Norwegian case, Table 1 outlines the distinguishing characteristics of both cases with regards to the preceding key discussion points.

Table 1: Norwegian and Brazilian petroleum industries

	Norway c.1975-1980	Brazil Today
Local content policy	One of many graded criteria in the bidding process that were aggregated overall	Mandatory targets
Domestic supplier engagement (beyond local content)	Technology agreements in concession contracts	No formalised regulation or requirement
University-MNE collaboration	Underwritten by Goodwill Agreements (i.e. private funded)	Supported through government-mandated private funding (1% Regulation) and sector-specific public funding

Contract basis	Concession	Production sharing
Socioeconomic status	Middle-to-high income; low inequality; very low unemployment; low national debt; moderate inflation; steady GDP growth	Middle income; high inequality; high unemployment; high national debt; high inflation; slowing GDP

In summary, the recent trajectory of the Brazilian petroleum industry is quite different from that pursued by the Norwegian government during the North Sea development. University-MNE collaboration has been prioritised over supplier involvement, with no government-mandated requirement or incentive for operators to engage with domestic suppliers beyond local content, such as the technology agreements that were so instrumental in developing indigenous capabilities and technologies in Norway. The local content policy is increasingly compromising on the pursuit of innovation and is at risk of repeating the sectoral failings of previous ISI administrations (i.e. diminished innovative capacity and international competitiveness beyond the national champion). The decision to select production sharing arrangements for the pre-salt supports the hurried development of the fields, to the detriment of domestic suppliers that need patient sectoral development to thrive. As the country ventures further into the pre-salt development, these will ultimately shape a very different future for Brazilian petroleum.

The policy learning evident in the Norwegian case offers an example of how the shortcomings of the Brazilian policy offering could be rectified. One possible resolution for the reconciliation of Brazil's policy demands is to redesign the two leading policies and have them work together. The 1% Regulation is a valuable policy intervention, clearly capable of generating huge sums of funding. Were these funds to be steered towards inter-firm collaborations (between operators and domestic suppliers), this may reap the kind of rewards (both nationally and sectorally) enjoyed through similar collaborations in the North Sea development. In the short-term, local content can be used to provide a market for the technologies generated through these collaborations. This would assist operators in fulfilling their local content requirements (including those in high-technology disciplines) and support the domestic supply sector as it develops valuable competencies and technology bases. However, local content targets should be reduced over time, so as to minimise the associated pitfalls (such as weakened productivity and innovative capacity), and should be supplemented with a long-term strategy to support the innovativeness and competitiveness of the domestic industry.

The paper offered three propositions for testing through examination of the two case studies. These are shown in Table 2, along with the supporting evidence from the preceding discussion, and concluding comments reflecting the extent to which each proposition was found to be true.

Table 2: Summary of case study evidence

Proposition	Key Evidence from Case Studies	Conclusion
<p>1. Conflicts can arise between the policy demands of national and sectoral systems of innovation. If not resolved, these can negatively affect the innovation performance of one or both of these systems.</p>	<p>Two competing sets of policy demands are evident in both cases:</p> <ul style="list-style-type: none"> • In the SSI, this includes the development of new petroleum technologies, accessing valuable foreign knowledge and technology bases, and enhancing the innovative capacity and competitiveness of the domestic supply sector. In the NSI, this includes strengthening the national university system, establishing spillovers with related industries, and improvement of the country's socioeconomic conditions. • Brazil emphasises investment in universities and the national champion, which supports the NSI and the pursuit of oil revenues; SSI is left behind by a hurried production schedule, low investment in domestic industry and lack of focus on innovation and competitiveness for domestic firms. Growth in the innovative capacity of the country (particularly universities) but not the sector. • Norway effectively managed the development of the SSI and NSI, so as to (respectively) support the development of advanced technologies and build an innovative and globally-competitive supply industry, whilst also providing for the broader economy, public universities and related industries. 	<p>The Brazil case shows little evidence of domestic innovative capacity building in the sector outside of Petrobras. This was recognised as a current weakness of the government's sectoral initiatives by several interviewees. A conflict exists between the policy demands of these systems, and this suggests that domestic innovation performance can suffer in those systems with neglected demands.</p> <p>Norway, under a similar scenario, was successful in reconciling these policy demands. However, the notion of an 'optimum state' between these competing demands is unrealistic. One reason for Norway's success was its ability to adapt and learn from its policy offering over time: this should be the aim of national government.</p>

<p>2. The reconciliation of national and sectoral innovation systems' policy demands requires the implementation of well-considered policy interventions.</p>	<p>Policy has shaped the innovation landscape in both cases:</p> <ul style="list-style-type: none"> • How much investment, from where, for whom, with whom, and for what activities. • Further, the extent of collaboration (and between whom) and role of domestic enterprise in the industry's growth. <p>Norway demonstrated a considered and reflective approach to policymaking, whereas, to date, Brazil's has been hurried and short-sighted.</p>	<p>Following the technology opportunities of both cases, two very different policy pathways were adopted, with equally different results for the respective national and sectoral systems of innovation.</p> <p>This underlines the pivotal role policy plays in the NSI-SSI intersection, and the need for a long-term, coherent approach to policymaking therein.</p>
<p>3. Following the identification of a large-scale innovation opportunity, Brazil has a tendency to neglect the policy demands of the sector, so as to pursue the policy demands of the NSI and goals for the improvement of the country's socioeconomic conditions.</p>	<p>The governmental interventions of Brazil demonstrate the prioritisation of the NSI and country's socioeconomic conditions over the demands of the SSI (particularly regarding domestic industry). Norway's patient and considered approach to a similar scenario may have been afforded them by a stronger socioeconomic environment.</p>	<p>Political and economic contexts matter in shaping the innovation pathways of countries and national industries (as observed previously by Engen (2009)). This does however require further investigation to substantiate.</p> <p>The Brazil case also demonstrates how sectors can be manipulated as a tool for national policymaking.</p>

The first proposition of the paper asserted that conflicts can arise between competing policy demands. Both case studies illustrate that national and sectoral systems of innovation have distinct and not necessarily complementary policy demands. A conflict can be observed in the Brazilian case, where sectoral policy initiatives have done little since the pre-salt discoveries to bolster domestic innovation in the SSI. Instead, recent growth in the sector has been used to support innovative capacity building in the NSI (particularly in universities). The latter was achieved in the Norwegian case – along with considerable spillovers into non-oil sectors (Bjørnland and Thorsrud 2014; Cappelen and Mjøset, 2013) – without neglecting the SSI's policy demands in the manner observed in the Brazil case. This conflict has had a detrimental effect on indigenous innovation in the Brazilian petroleum SSI (apart from Petrobras), with the current low level of domestic innovation either ignored (as with the 1% Regulation) or potentially exacerbated (as with the local content policy). Thus, there is adequate evidence here to support the first proposition.

Just as the prioritisation of the NSI's policy demands over those of the SSI will prove detrimental to the latter, the reverse can also be true. For example, had Norway focussed exclusively on supporting indigenous innovation and growing its domestic petroleum industry, thereby neglecting the NSI's policy demands, it would have failed to capture the knowledge, productivity, human capital and technology spillovers into other industries, and growth in its national universities and research institutes (refer Engen, 2009).

This highlights the challenge that is faced by policymakers in reconciling the demands of the two systems, as was questioned by the paper's second proposition. In both cases, policy can be seen to have played the pivotal role in shaping the innovation pathways adopted following the respective technology opportunities. Most significantly, in contrasting the two cases, policy defines the role domestic industry will take in capturing a technology opportunity. Brazil's rushed approach is notably different from Norway's considered approach. Several other researchers have similarly found the Brazilian system of innovation to be lacking long-term industrial policies (Cassiolato and Lastres, 1999; Katz, 2000; 2001; Marques and Oliveira, 2009).

The extent to which a conscious decision has been made by Brazilian policymakers to prioritise the policy demands of the NSI over those of the SSI is, regrettably, unclear from the interview data. Whereas Norway demonstrated considerable policy learning during the North Sea development, Brazil is currently engaging in policy decisions that look destined to repeat the country's past mistakes with protectionism. Policy learning is a crucial facet of reconciling these two systems' policy demands. The Norwegian case study demonstrates that these demands can be reconciled to an extent that is satisfactory from the perspective of both systems.

However, attaining an ‘optimum state’ is not a realistic policy goal. Rather, policymakers should look to develop the capacity and mechanisms to support the identification of policy inconsistencies, addressing them thereafter and learning from these experiences.

This leaves the question of what are the underlying factors behind the prioritisation of the NSI policy demands in the Brazilian case (refer to the paper’s third proposition). Comparing the Brazilian approach with that of the Norwegian government’s supports Engen’s (2009) position that the development of Norway’s petroleum industry would have taken another direction under a different political and economic context. The differing macroeconomic contexts are likely to be at the heart of the different directions taken by the two governments, whereby Brazil’s hasty development of the pre-salt fields is driven by the pursuit of near-term benefits for the NSI and a desire to address the country’s socioeconomic problems. However, this does require further investigation to substantiate.

Similar examples of exaggerated protectionism are common in developing countries (particularly Latin America), with a resulting negative impact on innovative capacity and international competitiveness in targeted sectors (Reinhardt and Peres, 2000; Roett, 1997). This suggests that conflicts of this nature are likely to exist elsewhere in Latin American and developing country contexts. This too is an area for further investigation.

Conclusions

This paper has offered a perspective on the systems of innovation theory that focussed on the intersection between systems, thus highlighting the dynamic between them. In doing so, the argument has been made that the evaluation of sectoral systems of innovation must be conducted with significant consideration of the national system under which they reside. These systems do not co-exist with one another effortlessly and complementarity between the policy demands therein is far from assured. There are different and often incompatible policy demands from each system. The historical case study illustrates that competing demands can nevertheless be reconciled successfully through effective policy intervention. This highlights the importance of complementarity between systems of innovation (and those systems’ guiding institutions). This complementarity is important to *both* systems, with shortcomings in the underlying policies of one system impacting upon the other. Heum et al. (2011) previously illustrated this, finding that while development of a domestic supply sector can hinder growth and increase costs in the short-term, it can benefit the NSI greatly in the long-term. If given time to mature, an SSI will provide opportunities for many other sectors via spillovers and result in broader economic development in the country (as evidenced previously in Norwegian petroleum; Bjørnland and Thorsrud 2014; Cappelen and Mjøset, 2013; Sæther et al., 2011).

There is clearly a considerable challenge in reconciling the policy demands of both systems and it is national government that plays a pivotal role here. The case studies highlight the need for policy and other governmental interventions to support a sector in addressing technological challenges at the time of a large development opportunity. It also demonstrates how such an opportunity can be missed through a lack of coordination with the national system under which it resides. Malerba and Mani (2009) previously found that government could act as either a facilitator or an obstacle in the development of an SSI. Given the nature of the government's dual role in the NSI-SSI intersection, it is able to act as a facilitator in an NSI, while at the same time being an obstacle in the SSI. Further, comparison of the two countries' local content initiatives illustrates that policy instruments that can appear to be similar in both design and intent can offer very different results. Each NSI-SSI configuration is unique, and as such, policy imitation (a common course of action for developing countries) will often struggle to achieve reconciliation of policy demands between two systems. Synergy between these two systems is very important: the policies designed to promote an SSI in a country should be intertwined and, most importantly, coordinated with those enacted in the NSI.

This raises an area for future research. The Brazil case suggests that other developing nations may also have a tendency to favour the policy demands of the NSI over those of underlying SSIs. This can be explained by the socioeconomic standing of such countries, where the need to address the needs of the larger population (e.g. reducing unemployment, pursuing national revenue from sectors) will be more pressing. The case is thus illustrative of the way in which a domestic sector can be manipulated as a tool for national policymaking.

The conflict observed in the Brazilian NSI-SSI intersection is a product, at least in part, of the macroeconomic conditions of the country. A trend of weak interactions in the systems of innovation of Latin American (i.e. developing) countries has been previously observed in Arocena and Sutz (2000). The findings of this paper suggest that a trend for weak interactions *between* systems of innovation may similarly exist under this context. It may be that the reconciling of NSI and SSI policy demands is more challenging in developing economies, and a conflict is therefore more likely to occur between two innovation systems under this context.

Considerably more research is needed into the NSI-SSI intersection, based on case studies from numerous different sectors and countries of varying levels of economic development, in order to fully elucidate the dynamic between systems of innovation and how competing policy demands can be reconciled by the state.

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Chapter 3: Emerging models of the entrepreneurial university: lessons from Brazil

Abstract

Academic entrepreneurship has been a topic of increasing interest for researchers over the last three decades. New university models are now appearing that extend considerably beyond the traditional notion of the entrepreneurial university, including the delivery of comprehensive entrepreneurship education modules across all faculties, and supporting students in creating new ventures. This paper captures the additional mechanisms, roles, drivers and outputs of this emerging entrepreneurial university model, and discusses the implications this holds for researchers, academic institutions and policymakers, both within the case study country and beyond. A framework is presented to support this investigation, which combines a taxonomy of resources with a stage-gate model of an entrepreneur's development. The findings are primarily drawn from interviews with start-up founders and incubator and science park managers from three of Brazil's leading universities. The research reveals a diverse and far-reaching portfolio of mechanisms, the involvement of a greater number of actors and stakeholders, and a broader remit of socioeconomic betterment. The paper concludes by calling for further research into this emerging model, particularly around the role of entrepreneurship education.

Introduction

The importance of traditional universities (i.e. those that engage primarily in knowledge dissemination and research activities across both student and academic communities; O'Shea et al., 2005) has been comprehensively addressed in the literature (Bok, 2009; Geiger, 1993; Newman and Turner, 1996). Universities are a primary source for new knowledge creation and innovation (Brennan and McGowan, 2007) and participate in the innovation process through several mechanisms, including publishing academic works, contributing to innovation networks (i.e. regional/sectoral/national systems of innovation), and the training of engineers and scientists (Eveland, 1985; Rogers, 1986). Traditional universities have been seen to further the technology transfer process indirectly by providing qualified personnel and specialised knowledge to industry (Carayannis et al., 1998).

Over the last three decades, however, it has been shown that traditional universities can play a significantly larger role in regional and national development (O'Shea, 2007). Universities can contribute to regional and national development in the form of new business creation, growth

in existing firms, and an increase in employment opportunities (Ndonzuau et al., 2002; Siegel et al., 2003b; Steffensen et al., 2000). The modern university now takes on a multifaceted role, involving technology transfer to industry, the creation of university spin-off companies, and the management of science parks and incubators, amongst others.

Recently, interesting cases have emerged of universities further extending this model of the 'entrepreneurial university' (refer Etzkowitz, 2013b; 2015; Ortega and Bagnato, 2015; Siegel and Wright, 2015a; 2015b), including creating and nurturing new firms, and placing a much greater emphasis on entrepreneurship education (both prior to, and following, firm creation). However, this emerging model of the entrepreneurial university is yet to be adequately depicted in the literature. This calls for an analysis of several new entrepreneurial university models, to capture the mechanisms, roles, drivers and outputs underlying this development. The objective of the paper is to examine these dynamics (and how they differ from the mainstream literature's perception of what an entrepreneurial university is), in addition to discussing the broader implications this holds for researchers, academic institutions and policymakers. The research challenges doubts in the literature as to whether such activities can become an explicit mission of universities (Geiger and Sá, 2008).

The analysis is drawn from fieldwork conducted in Brazil in 2014 and 2015 against the backdrop of a large natural reserves discovery: the 'pre-salt' oil. This oil resides at over 7000 metres below the sea surface and around 300 kilometres from the south-eastern coast of Brazil. The reserves offer great potential to the country, not only as a source of macroeconomic growth but also for innovation and domestic industry development. This has been addressed through several governmental interventions, referred to here as 'top-down' interventions (described in the previous chapter). However, the focus of the paper is the 'bottom-up' initiatives created by public universities in the country. This is explored through semi-structured interviews with some of the beneficiaries of these initiatives: the entrepreneurs of university-hosted incubator and science park firms; and the management teams of university incubators and science parks. This leads to a comprehensive taxonomy of the resources available to entrepreneurs, and forms the basis for analysis in the latter part of the paper.

The next section discusses the theoretical framework, focussing on academic entrepreneurship, university spin-offs and the Triple Helix model. The research design and analytical framework are then presented. This is followed by a discussion of academic entrepreneurship in Brazil, and a brief overview of the innovation funding landscape in Brazilian petroleum. The empirical data is then analysed in accordance with the research framework, including a summary section of the key findings and broader implications. The final section outlines the conclusions and future areas for research.

Literature Review

This literature review discusses the three theoretical frameworks that guide the research: academic entrepreneurship; university spin-offs; and the Triple Helix model. This will be followed by the presentation of the study's conceptual framework and research design.

Academic Entrepreneurship and the 'Entrepreneurial University'

The last three decades have seen a significant rise in the commercialisation of research outputs and other forms of technology transfer from universities (Siegel and Wright, 2015b), termed 'academic entrepreneurship'. Such an endeavour (and the involvement of national governments therein) was not well established prior to 1980 (Shane, 2002). However, having recognised the benefits of commercialising university inventions (e.g. increases in national revenue and job creation), several national governments adapted their technology policy focus from a 'market failure' model (which assumes little participation of universities or government in the innovation process) to that of a cooperative approach (that assumes academia and the state can play a positive role in the process (Djokovic and Souitaris, 2008). In the United States, this is evidenced, in part, by the enactment of the Bayh-Dole Act in 1980, which incentivised commercialisation initiatives from universities, including the foundation of a uniform patent policy across federal agencies, and the removal of many restrictions to technology licensing (Grimaldi et al., 2011). This was supplemented in the 1980s and 1990s by other policy measures, such as the change to patent policy (which expanded the use of government technology), relaxation of anti-trust regulations, and promotion of cooperative R&D (Bozeman, 2000). Financial support mechanisms were also offered in the form of grants and public funding (Djokovic and Souitaris, 2008), some of which were focussed specifically on funding innovative new companies in their infancy (such as the Small Business Innovation Research and the Small Business Technology Transfer Research funds, which remain active to this day). Many other countries have followed suit in passing laws promoting the patenting of publicly-funded research, including those in the developing world (such as China, India, South Africa and Brazil; So et al., 2008).

Early efforts in academic entrepreneurship saw the increasing trend of establishing a technology transfer office (TTO) at universities, primed with the objective of securing intellectual property protection of university inventions, assessing market opportunities for these inventions, and negotiating licensing agreements. Accordingly, the primary focus for universities was patenting and licensing. The creation of new enterprises as a means of commercialising research outputs was paid little attention, as this would have distracted from the potentially lucrative patent licensing arrangements with industry (Siegel and Wright,

2015a). The role of the TTO was later broadened to increasingly support the creation of spin-off companies (university spin-offs; Roberts, 1991; Roberts and Malone, 1996). This will be discussed further in a subsequent section.

Today, many universities also establish science parks and business incubators as a mechanism to support technology transfer and academic entrepreneurship efforts. A science park usually refers to a collection of R&D facilities for companies (both domestic and foreign; small and medium-sized enterprises (SMEs) and multinational enterprises (MNEs)). It will often look to generate a culture of technology development, cooperation and knowledge exchange between the resident firms, and will typically offer a shared infrastructure of technical, logistical, administrative and financial support to young firms (Guy, 1996). Proximity to universities and other public research institutes provides tenanted firms with easier access to scientific expertise and research results, thereby supporting technology transfer and the adaptation of research into commercial products/services, as is the nature of spillovers (Colombo and Delmastro, 2002). Acs et al. (1994) found these spillovers to be more pronounced in SMEs. Science parks have been promoted as a tool for technology transfer and regional development, creating new jobs and technology-driven firms, and helping to boost local economies (Uyarra, 2010). However, some researchers have found inconclusive evidence as to the resident firms' innovative activity (Westhead, 1997) and the quality of relationships with universities (Massey et al., 1992).

Incubators are a similar concept but are often focussed on spin-offs and comprised of multi-tenant buildings rather than individual company R&D facilities (or technology centres). Incubation will typically provide a shared infrastructure and business support services to aid the development of resident firms during the first few years of activity. This is aimed at addressing the high failure rate of new ventures, which, in the vast majority of cases, is due to a lack of financing, poor management, or a lack of understanding of the marketplace (Lewis, 2001). Support services offered by incubators often consist of a mix of administrative, consulting, physical and training services (Chandra, 2007). Cooper (1984) found that incubators affect the spin-off rate and success of new companies through mentoring services and providing human capital support (cited in Djokovic and Souitaris, 2008).

Besides the provision of resources and services, the incubator is also crucial to establishing networks (Smilor and Gill, 1986). It is this role that distinguishes incubators from business parks, where typically only premises and basic services are provided (Hansen et al., 2000). Some researchers have highlighted this networking role as a key determinant in successful incubation (O'Neal, 2005). Incubators also ease the process of commercialising university research efforts for academics (Colombo and Delmastro, 2002).

This, then, is the ‘traditional’ model of academic entrepreneurship: the commercialisation of academic research outputs and creation of spin-offs through a combination of a technology transfer office, business incubator and science park.

Where a university has an explicit mission of economic development in addition to research and teaching, it is referred to by many researchers in the field as an ‘entrepreneurial university’ (Clark, 2001; Etzkowitz et al., 2000). Economic development is thus referred to as the ‘third mission’ of universities (e.g. Gulbrandsen and Slipersæter, 2007; Laredo, 2007; Philpott et al., 2011). Such is the acceptance of this third mission amongst many universities in the developed world, academic entrepreneurship performance is benchmarked against metrics such as patenting and licensing activity and the creation of spin-off companies (e.g. AUTM, 2015 in the United States), much in the same manner as teaching and research performance is.

The move of universities to a more entrepreneurial model has its detractors. The term ‘academic capitalism’ has been used to describe a pessimistic perspective of the phenomenon, exemplified by the work of Slaughter and Rhoades (2004; 2008). The authors raise concerns over the commercialisation of research – particularly the loss of academic freedom and autonomy (also Harris, 2005) – and resent the influence of industry in academia. However, despite concerns that a focus on the third mission leads to less basic research in academic institutions (Feller, 1997; Slaughter and Leslie, 1997; Feldman and Desrochers, 2003; 2004), several researchers have found the opposite is true (summarised in Siegel and Wright, 2015b). Geiger (2004) observed a cycle of funding, whereby gains from commercialisation activities are reinvested into basic research efforts. Furthermore, Kleinman and Vallas (2001) suggest that academic autonomy can emerge from increasing university-industry collaboration, whilst Brint (2005) argues that an improved funding profile from the third mission can be directed at self-supported research, which also enhances a researchers’ autonomy. Geiger (2004) also suggests that valuable knowledge exchange can occur from interaction between faculty and industrial partners.

Clark (1998) analysed five universities that were driven by an entrepreneurial objective (Warwick in England, Strathclyde in Scotland, Twente in the Netherlands, Chalmers in Sweden, and Joensuu in Finland), and identified five facets of a successful model of an entrepreneurial university:

1. A ‘strengthened steering core’, which “must embrace central managerial groups *and* academic departments” (emphasis in original), with employees empowered to make decisions under a flat organisational structure (refer Clarke, 2004 also);

2. An 'expanded developmental periphery', including organisational units outside of traditional academic departments engaged in industry outreach, knowledge transfer, intellectual property protection and marketing;
3. A 'diversified funding base', particularly 'third-stream income' (i.e. that from sources other than governmental bodies or research councils), which may include royalty income, funds from industry actors and charities, and alumni fundraising, which can be expended with a greater degree of freedom;
4. A 'stimulated academic heartland' that "accepts a modified belief system". The focus here is on reconciling the new commercial interests of the university with traditional academic values. Academic units become entrepreneurial units and actively pursue engagement with external actors and potential third-stream income sources. This requires academic staff to accept a greater degree of managerial authority, whilst central managers of the university must balance steering the university in new directions with maintaining academic freedom;
5. An 'integrated entrepreneurial culture' involves establishing a climate and ethos of entrepreneurialism throughout all levels of the university. Clark emphasises that this is a complex and significant task, as universities are often inflexible to change of this nature and cling to traditional academic norms. As such, universities must first learn how to embrace change before such a culture can be instilled.

Clark (2004) acknowledges that not all universities will undertake this transformation into an entrepreneurial university. Some universities possess an active resistance to entrepreneurialism, whilst others will perceive the risks involved in starting new ventures to be too great; some will be constrained by inertia, whilst others will not act under a belief that governmental funding will eventually increase (summarised in de Zilwa, 2007). Other common barriers include: an exclusive focus on basic research; an active opposition to change; silos of knowledge (i.e. an unwillingness to share knowledge and/or technology); and the absence of facilitators (Chukumba and Jensen, 2005; Schulte 2004; Schutte 1999; cited in La Paz et al., 2010).

The transition of many universities to more entrepreneurial models is part of a broader evolution of universities into major contributors to economic development. Crow and Dabers (2015) attest that the 'New American University' is one in which students and faculty utilise knowledge to serve broader society and local communities. The authors offer evidence from the United States which suggests that universities will reduce the emphasis on traditional notions of prestige, instead pursuing diversification, innovation and uniqueness. This attracts alternative rewards such as more and better-prepared students, a greater degree of political

support and increased financial resources (summarised in Lawson, 2016). Such a notion is termed elsewhere by Goddard et al. (2012) as the ‘civic university’. Similarly, Youtie and Shapira (2008) observed that whilst traditional universities will often regard themselves as silos for existing knowledge, modern universities will pursue opportunities for new knowledge creation, technological innovation and regional economic development. The particular significance of such studies to this paper is the increasing emergence of new university models and initiatives, and the quest for differentiation between universities. As Crow and Dabars (2015) attest, “the public research university is a highly successful model, but this does not diminish the imperative for new and differentiated models that more squarely address the needs of the nation in the twenty-first century”.

This notion of universities as significant proponents of local economic development (and more broadly, regional development, including non-economic advancement), can be conveyed through several different lenses. Trippel et al. (2015) distinguish between the entrepreneurial university model described here and three other conceptual models: the Regional Innovation System (RIS) University Model; the Mode 2 University Model; and the Engaged University Model. The authors demonstrate that these four models emphasise very different activities and outputs in the pursuit of regional development:

- **Entrepreneurial University Model:** As has been discussed, universities are increasingly focussed on a third mission in addition to research and teaching - economic development. This takes the form of new jobs, new companies and knowledge sharing, derived from the commercialisation of research outputs. A university's success in commercialising its research outputs is not a guarantee of regional development; similarly, this success is the result not only of endogenous efforts within the university but also the region's strengths with respect to local knowledge networks (Casper, 2013), sectoral specialisation (Feldman, 2003) and industrial R&D intensity (Agrawal and Cockburn, 2003).
- **RIS University Model:** As the name implies, this is an extension of the Regional Innovation System (RIS; refer Cooke et al., 1997; Asheim and Coenen, 2005) concept, which emphasises the important role of universities to localised innovation activities as knowledge creators and disseminators. This focus on knowledge exchange between universities and industry is similar to that described by the Entrepreneurial University Model, although the RIS University Model considers a wider set of mechanisms, such as formalised collaborations and informal interactions (Trippel et al., 2015). The RIS concept describes the transfer of knowledge from universities to local firms as a core part of their strategy (Uyarra, 2010). However, from this perspective, the innovative

and absorptive capacity of the system's other elements is central to the utilisation of university outputs, rather than the university's strategies, activities and organisational capabilities (Tripl et al., 2015).

Whilst the above two models focus on the contribution of universities to economic development within regions, the following two models adopt a broader perspective of regional development that also includes social, cultural and societal factors:

- **Mode 2 University Model:** The 'new production of knowledge' theory (NPK) described by Gibbons et al. (1994) identifies a second form of knowledge production in universities (mode 2) that differs from the traditional conceptualisation of this process (mode 1). Whereas mode 1 knowledge production can be characterised as driven by scientific knowledge and conducted within distinct disciplines, mode 2 knowledge production is multidisciplinary and context-driven (i.e. carried out in consideration of the regional environment and the societal challenges it poses; Nowotny et al., 2001). Nowotny et al. (2001) identify changes to university and research funding as an important factor in the emergence of mode 2, whereby a scenario of constrained national funding has led university research to increasingly be directed at potential solutions for current industrial, political and societal challenges. It is in this regard that universities contribute to regional development.
- **Engaged University Model:** This model conceptualises the university as a repository of knowledge and expertise that can be deployed to address regional needs (Uyarra, 2010). The university plays an active role in shaping the regional identity and addressing the challenges of local industry and society (Breznitz and Feldman, 2012). Engagement has been observed to take a multitude of forms, such as regional teaching programmes, local student recruitment, retention of graduates, the formalised inclusion of regional priorities in university strategy, coordination with regional networks, policy advice and support services to local firms (Gunasekara, 2006; Tripl et al., 2015).

For a researcher, the four models can offer different perspectives on the same phenomenon, or can otherwise be used in unison as the basis for a cross-case analysis of several countries' university systems (as in Tripl et al., 2015). The Entrepreneurial University model has been chosen for this study for several reasons. First, as the research is focussed on university-led technological progress and the economic development stemming from this, social, cultural and societal factors – as addressed by the Mode 2 University and Engaged University models – are not of relevance here. Secondly, the paper does not adopt a systemic view in analysing the case study universities. Rather, it is focussed on the bottom-up, endogenous initiatives of universities and underlines the significance of their internal strategies, activities and

organisational capabilities (in reference to Trippel et al., 2015 above). The RIS University Model, in contrast to the Entrepreneurial University Model, demotes the significance of university policy, emphasising instead the role of regional policy; it focusses on the regional system, rather than organisational structures; and regional networks and systems are the main unit of analysis, rather than the university (Uyarra, 2010). Finally, whilst the RIS model is supportive of a key finding of this paper – the significance of a broader set of third mission activities beyond the licensing of patents and creation of spin-offs, including formalised collaboration and informal interactions (Trippel et al., 2015) – the focus is nevertheless on the new modes of commercialising research outputs. This is the mainstay of the Entrepreneurial University Model.

It is important to understand these four models, as the Brazilian university system has a strong history of contributing significantly to regional development (discussed momentarily). The paper also draws conclusions as to the extent to which this is an objective of the emerging model of the entrepreneurial university. Other researchers wishing to follow up this study's implications with regards to regional development may wish to examine it from a different perspective, such as one of the three outlined above.

The existing literature on entrepreneurial universities offers insights into the transformation of developed country universities into more commercially-active models (for example, the United States in O'Shea et al. 2005; O'Shea, 2007; Europe in Clark, 1998; Wright et al., 2007). However, the literature on entrepreneurial universities in a developing country setting is limited (Etzkowitz and de Mello, 2004; Guerrero et al., 2014). One valuable assertion comes from La Paz et al. (2010), who state that the entrepreneurial university model may be particularly difficult to replicate in a developing nation, where cultural barriers and limited resources impose additional hindrances to the complex, risk averse and slow-to-respond institutions that are comfortable in their pursuit of the first and second missions. The authors contend that in developing country universities, the move to a more entrepreneurial model is often initiated by small units that transmit and spread their vision across entire institutions.

Brazil is something of an exception in the developing world, as several of the country's leading universities have been engaged in academic entrepreneurship for over three decades (Etzkowitz et al., 2005; Mello et al., 2011). For example, one of the case study universities– COPPE-UFRJ – established a consulting services department, COPPETEC, in 1973, followed by a business incubator in 1994, and a technology transfer office in 2001. Outside of the country's leading universities, however, the practice of commercialisation is still in its infancy.

Brazil's model of academic entrepreneurship is described by Etzkowitz (2015) as a synthesis of the variants from the United States and Europe. However, whilst universities in North America and Europe are entwined with an extensive variety of companies through comprehensive and wide-ranging agreements, this is not the case in Brazil (Ortega and Bagnato, 2015). There are weak linkages with industry in the Brazilian system, which the authors attribute to domestic companies generally not being focussed on the opportunity to utilise research outputs from universities: a process that may be constrained by bureaucracy and an inability of the university to deliver on a partnership agreement in a timely fashion. This leaves most Brazilian universities with a reduced number of willing potential partners with which to engage. Universities are recognised as an excellent source of knowledge in many developed countries. In Brazil, the onus is on the universities (supported by various government incentives) to create partnerships with industry.

The Brazilian university incubator sector has a history of focussing on low-tech services, as opposed to high-tech firm development, as a way of addressing broader national and regional socioeconomic weaknesses (Etzkowitz, 2015). This is exemplified by the 'Popular Cooperatives' initiatives in many of the country's universities: a programme for incubating worker cooperatives and a means by which academic entrepreneurship is translated to a non-academic population (ibid; also refer Almeida et al., 2010, where it is characterised as 'social innovation'). Such initiatives (termed Technological Incubators of Popular Cooperatives, or ITCPs) develop programmes in domains such as cleaning, cooking and civil construction to engage with local deprived communities that do not have access to higher education (Leca et al., 2014). The first of these ITCPs was established at COPPE-UFRJ in 1995 in response to Brazil's increasing levels of unemployment, and utilised retired university support staff residing in local favelas to recruit participants (Etzkowitz, 2015). To date, the COPPE-UFRJ ITCP has reached more than 1200 people in Rio de Janeiro city, having incubated 125 cooperatives, and has supported the diffusion of this model to other universities (there are currently forty-two such ITCPs across Brazil; Leca et al., 2014).

A traditional model of the entrepreneurial university was described earlier in this literature review: one that centred around a technology transfer office, business incubator and science park. However, similar to the findings of Crow and Dabars (2015) in their broader study of the American university sector, new models of the entrepreneurial university are also being developed so as to meet the changing needs of society. Several authors have found that in addition to academic faculty and post-doctoral researchers becoming entrepreneurs, students too are forming new ventures whilst undertaking their studies (Etzkowitz, 2013a; Ortega and Bagnato, 2015; Siegel and Wright, 2015a). These authors have also observed that

socioeconomic development is as much a key driver for academic entrepreneurship as the traditional objective of commercialising research outputs as a valuable revenue source. In addition to the traditional trio of mechanisms – a technology transfer office, business incubator and science park – researchers have identified additional mechanisms, such as alumni networks (Etzkowitz, 2013a; Siegel and Wright, 2015a) entrepreneurship education and the creation of an ‘entrepreneurial ethos’ (Etzkowitz, 2013a; Ortega and Bagnato, 2015) and accelerator programmes (Siegel and Wright, 2015a). Beyond patents, licensing agreements and spin-off companies, emerging model outputs include university-firm collaborative partnerships (Etzkowitz, 2013a; Ortega and Bagnato, 2015; Siegel and Wright, 2015a), academic-commercial hybrid organisations (Etzkowitz, 2013a) and student companies (Siegel and Wright, 2015a).

The objective of this study is to utilise three of Brazil’s leading universities to explore this emerging model of academic entrepreneurship further, and to discuss the broader implications for researchers, academic institutions and policymakers. Research such as this is timely in capturing the emerging entrepreneurial model – both theoretically and empirically – so as to support future research on this topic. It is also important to note that there is a lesser body of literature addressing how universities in developing countries practice innovation (Ortega and Bagnato, 2015) and develop academic entrepreneurship capabilities (Etzkowitz and de Mello, 2004; Guerrero et al., 2014).

Two research questions drive the investigation:

1. What are the mechanisms, roles, drivers and outputs that comprise the emerging entrepreneurial model?
2. What implications does this emerging model have for Brazil and other developing countries?

One of the most significant mechanisms within an entrepreneurial university is the creation of new ventures: university spin-offs. Such an endeavour is the subject of a considerable body of literature, which will now be discussed and will later contribute to the formation of the research framework.

University Spin-offs

In the past, universities have passively licensed their technologies to large companies (Siegel et al., 2003a). Today, it is increasingly common to utilise other mechanisms of technology transfer that involve a more active role for the university, such as the creation of new companies (Chapple et al., 2005; Powers and McDougall, 2005). This process is known as ‘spinning off’;

the companies created through which are 'spin-offs'. A spin-off is founded with the objective of bringing one or more inventions established in the R&D facilities of another organisation (known as the parent organisation) to market (Verbano et al., 2015). Where the parent organisation is a university, the company may be referred to as a university spin-off (USO).

A common mechanism for the creation of USOs is the university TTO. The number of spin-off companies emerging from a university has been found to be positively associated to the size and capabilities of the TTO, the university's expenditure on R&D activities and intellectual property protection, and the royalty regime of the university (Lockett and Wright, 2005; Powers and McDougall, 2005). Powers and McDougall (2005) also found a strong correlation between spin-off intensity and the investment of industry in technology transfer programmes. Faculty from leading universities may also find it easier to attain the resources required to spin off for reasons of credibility (Di Gregorio and Shane, 2003).

Birley (2002) identified the academic environment as the most complex in which to pursue entrepreneurial endeavours. Several researchers have examined the barriers to university participation in the creation of spin-offs. These barriers are related to the more traditional role of the university as a knowledge creator, which can be in conflict with the more enterprising, industry-driven role, thereby creating inefficiencies in technology transfer and spin-off activities. Thursby and Kemp (2002) found that less than half of university inventions with commercial potential were disclosed to the TTO. This may be because the inventor does not realise the commercial potential of the technology (Chapple et al., 2005), or may otherwise be due to a non-supportive culture (e.g. 'publish or perish'), inhibitive bureaucracy, ineffective reward systems, or poorly managed TTOs (Ndonzuau et al., 2002; Siegel et al., 2003b). Siegel et al. (2004) find that in order to support technology transfer, universities should focus on the following factors: reward systems; staffing practices of the TTO; flexibility in the university's technology transfer policies; additional resources for technology transfer (where consistent with the university's objectives); and eliminating cultural and informational barriers.

The creation of a USO can emerge from the transfer of technology and/or people (Djokovic and Souitaris, 2008). Technology can either refer to: intellectual property (e.g. patents), whereby "a new company [is] founded to exploit a piece of intellectual property created in an academic institution" (Shane, 2004); or university-generated knowledge (codified or otherwise), where a "new firm [is] created to commercially exploit some knowledge, technology or research results developed within a university" (Pirnay et al., 2003).

Many definitions of spin-off companies encompass the transfer of people, as well as technology. The pioneering studies of spin-offs in the 1960s and 1970s do not consider a

company a spin-off unless accompanied by personnel from the parent organisation (Cooper, 1971; Roberts, 1968; 1970; Roberts and Wainer, 1968). This definition (i.e. the transfer of technology *and* people) has since been challenged by several researchers. Smilor et al. (1990) offer two conditions: “(i) the founder was a faculty member, staff member, or student who left the university to start a company or who started the company while still affiliated with the university; and/or (ii) a technology or technology-based idea developed within the university”. This definition is broader than those that do not encompass students (e.g. Carayannis et al., 1998; Steffensen et al., 2000) but it does not account for the possibility of transferred personnel remaining at the parent organisation, nor does it emphasise the significance of the technology transfer process. These are important considerations in discussing the USOs interviewed for this study and, for this reason, the following definition of spin-off from Nicolaou and Birley (2003) will be used: “(i) the transfer of a core technology from an academic institution into a new company and (ii) the founding member(s) may include the inventor academic(s), who may or may not be currently affiliated with the academic institution”.

However, even in adopting a definition, the boundaries of the spin-off (and by extension a USO) remain unclear, with all USOs being regarded in the same manner. For this reason, several studies have proposed typologies of USOs. Hindle and Yencken (2004) classify USOs with regards to their relationship with the university: (i) direct spin-off, created to commercialise university-created intellectual property; (ii) technology transfer companies, founded to exploit the university’s tacit knowledge; (iii) start-up or indirect spin-offs, established by former/present faculty and/or students without formal licensing of intellectual property; (iv) spin-ins (to existing companies), which are new ventures based on the exploitation of new knowledge generated by the university.

Besides the knowledge transfer relationship between the university and the USO, there is another interesting dynamic to consider: the status of the individuals involved in the new venture. These two dynamics are captured in the typology of Pirnay et al. (2003), shown in Figure 6 below.

The model distinguishes between entrepreneurs with a scientific background (i.e. professors and academics) and those without substantial research experience (typically students). The knowledge transferred to the USO can be codified or tacit. Codified knowledge is usually distinct from the researcher(s) who developed it, whereas tacit knowledge (i.e. experiences and technical expertise) tend to be associated with the researcher who acquired it (Tietz, 2013). USOs based around codified knowledge have been found to be more product-oriented, whereas USOs exploiting tacit knowledge often operate in the service sector (Pirnay et al., 2003).

		Individual Status	
		Researcher	Student
		(Academic spin-off)	(Student spin-off)
Nature of knowledge transferred	Codified (Product-oriented spin-off)	Type I	Type III
	Tacit (Service-oriented spin-off)	Type II	Type IV

Figure 6: Typology of university spin-offs (Pirnay et al., 2003)

There is increasing diversity in the type of start-ups at universities (Shah and Pahnke, 2014), which includes a rapid increase in the creation of student start-ups (Siegel and Wright, 2015a). Moreover, this has included growth in student companies that are not based on university-owned formal IP. Such ventures are typically less demanding with regards to financing needs but may require support of a softer nature in order for them to grow and create financial, economic and social value (Siegel and Wright, 2015b).

Several studies have utilised stage-gate models to outline the phases of development for a USO, and the managerial competencies required and organisational behaviours exhibited by entrepreneurs. These have included three (Smith et al., 1985), four (Flamholtz, 1986; Ndonzuau et al., 2002) and five stages of development (Van de Ven et al., 1984; Vohora et al., 2004). The Vohora et al. (2004) is particularly enlightening as it identifies not only several stages of development – (i) research; (ii) opportunity-framing; (iii) pre-organisation; (iv) reorientation; and (v) sustainability – but also offers four ‘critical junctures’ that lie between these stages and must be overcome in order for the company to succeed:

1. Opportunity recognition, which spans from the research phase (in the parent organisation) to the recognition of the market opportunity, including the verification of the technology and mapping of the opportunity;
2. Entrepreneurial commitment, where a business plan is established, and resources and entrepreneurial capabilities are identified;

3. Credibility, where the business plan is reoriented in pursuit of the required human and financial resources, for which credibility is critical. The issue of credibility is more of a concern for USOs than many other start-ups;
4. Sustainable returns, in which the activities of the firm are now focussed on generating revenue and establishing the firm within the marketplace.

The model, whilst framed as a stage-gate process, is also informed by a second perspective on the development of USOs: the ‘resource-based view’, which considers the firm to be an historically determined collection of resources that are tied semi-permanently to the firm’s management (Wernerfelt, 1984). Teece et al. (1997) distinguish between stock resources (such as intellectual property) and dynamic capabilities (those being the ability to develop new competitive advantages, functional competences and organisational skills to match the requirements of a changing environment). The authors note that companies can possess a large stock of valuable technological assets without holding any useful capabilities. The notion that a firm’s competitive advantage emerges from both the exploitation of existing resources and the acquisition of new resources has been seen previously in Penrose (1959) and Wernerfelt (1984). A perspective such as this supports the view that in order to progress through the development stages, USOs must develop a necessary body of resources and internal capabilities over time (Vohora et al., 2004). As such, a deficiency in resources can constrain the development of a USO (West and DeCastro, 2001) – which may be exacerbated by an un-entrepreneurial environment – and is often responsible for the failure of the venture (Verbano et al., 2015).

The Vohora et al. (2004) model will form the basis of the study’s research framework (discussed in a subsequent section). The research framework will adopt a resource-based view, so as to capture the resources that are endowed to USOs from the parent university at each stage. The Vohora et al. (2004) model was selected for several reasons. First, as the model is USO-focussed, this aptly reflects the increasing emphasis on USOs as part of academic entrepreneurship, and the broader and more active role universities are adopting in supporting USOs. Secondly, the model captures the complete spectrum of entrepreneurial activity: from the moment a student first considers the possibility of starting a company (termed later as ‘entrepreneurial awareness’), to supporting the creation of that company, and beyond to assisting the company grow in the marketplace. Thus, it reflects the increasing role of entrepreneurship education in emerging entrepreneurial university models and the changing nature of support, from firm creation to a position of firm survival and growth. Finally, USOs are a valuable data source and the model supports their inclusion in the analysis. With reference to the two research questions above, whilst the underlying drivers can only be captured from

the universities, the gathering of data from USOs offers a unique perspective as to the mechanisms, roles and outputs involved in the firm's creation and subsequent growth. The selected companies were at different stages of development and had received varying levels of support from the parent university, thus offering insight into how the parent university's role has changed over the last several years.

Djokovic and Souitaris (2008) identify four types of resources required by USOs: technological, human, social and financial. However, whilst this taxonomy captures the resources offered by a traditional entrepreneurial university, the recent literature alludes to resource types beyond these four in emerging models (Etzkowitz, 2013a; Ortega and Bagnato, 2015; Siegel and Wright, 2015b). Therefore, an expanded taxonomy of resources will also be developed.

These resource endowments are important because, in comparison with other types of start-ups, USOs face further specific challenges (Vohora et al., 2004): universities typically lack resources and academic entrepreneurs may lack commercial skills; and conflicting motives of key stakeholders (such as the university, the entrepreneur, the USO's management team, and finance providers) may adversely influence the firm's progress from one stage to the next. However, once established, a USO can enjoy numerous benefits from maintaining its links to the parent organisation, such as access to laboratory facilities and research equipment (Steffensen et al., 2000), and access to human capital and market and technical knowledge (Rappert et al., 1999). USO-university relationships are more effective due to a high degree of trust and informality (Johansson et al., 2005; Roberts, 1991). Rappert et al. (1999) also found that, as a result of their origins, USOs had a wider range of contacts and placed a greater emphasis on relationships with universities than non-university spin-offs. Nevertheless, the USO-university relationship has been seen to decline over time, with many USOs focussing to a greater degree on customer relationships after the first few years of activity (Perez and Sánchez, 2003).

Even in contrast to other start-ups, USOs have been found to be important to industry in providing high-technology solutions, and to a national economy as a significant source of wealth creation, social capital gains and job opportunities (O'Shea, 2007; Shane and Stuart, 2002; Steffensen et al., 2000). Shane (2004) found that USOs are a more significant new job source and over one hundred times more likely to go public when compared to the average new company (in the United States).

The Triple Helix

The entrepreneurial university is neither created, nor does it exist, in isolation. It is a core component of a national innovation system (Etzkowitz and Leydesdorff, 2000; refer Freeman (1987), Lundvall (1992) and Nelson (1993) for national systems of innovation), interacting with industries and governments to increase the social benefit of its research outputs through knowledge and technology transfer (La Paz et al., 2010). These three components – academia, industry and government – are known as the Triple Helix (refer Etzkowitz and Leydesdorff, 2000; Leydesdorff, 2000). Thus, universities – and particularly entrepreneurial universities – play an important role in the Triple Helix.

The Triple Helix model stands in contrast to the traditional perception of a university's role in society, which describes a linear, one-way flow of knowledge from basic to applied research, and onwards thereafter to product development. The model suggests that knowledge flows in two directions, with the three components interacting recursively. The components are related to one another, existing within a domain of overlapping boundaries, with each performing the functions that were previously the remit of the other, and hybrid entities emerging at the points of interface (Etzkowitz and Leydesdorff, 2000).

As a framework for empirical study, the Triple Helix model provides “a heuristic method for studying the complex dynamics in relation to developments in the institutional networks among the carriers” (Leydesdorff and Meyer, 2006). It adds clarity to the dynamics and relations between diverse groups of actors, whilst providing a tool for relating to the different perspectives (Zheng, 2010). This is the purpose for which it is utilised in this paper.

Whilst the model has been criticised for attempting to blur the boundaries between universities, industry and government (e.g. Raman, 2005), it does emphasise the distinctive functions of each component within an economy (Leydesdorff and Meyer, 2006; Zheng, 2010). Leydesdorff (2005) argues that these components need be neither fully integrated nor completely differentiated: it is this tension between integration and differentiation that fosters technological and economic progress. Changes occur both within each of the institutions and the interfaces between them over time, which itself also drives development (Leydesdorff, 2005). Along with a two-way flow of knowledge, a two-way flow of influence also exists. As the relations between universities, industrial sectors and governmental bodies changes, so too does the internal structure and strategy of the entrepreneurial university (Zheng, 2010).

The notion of the entrepreneurial university is inherently linked to that of the Triple Helix. Under such a model, the university adopts an enhanced role in society that extends beyond education and scholarship, bringing the university closer to the end users of the knowledge

created, and establishing the university as an economic actor in its own right (Etzkowitz, 1998; 2004).

It is thus a Triple Helix of interactions between (entrepreneurial) universities, industry and government that is hypothesised to offer the optimum conditions for innovation performance (Zhou and Peng, 2008). University science parks, incubators and USOs are innovative organisations, the significance of which underscores the important role of entrepreneurial universities to regional development in knowledge-based economies (Etzkowitz and Leydesdorff, 2000). An entrepreneurial university is well placed to achieve indigenous innovation due to such organisations, as well as its increased service function to the economy and its stronger influence on society in contrast to that of a research university (Zhou and Peng, 2008). As a site of advanced knowledge, universities also hold the greatest potential to realise discontinuous/disruptive technological progress (Etzkowitz and Viale, 2010). As government will often focus on existing clusters, and industry will focus on incremental technological advances (Goldfarb and Henrekson, 2003), the onus is on universities to develop internal capabilities to fund the creation of new ventures (Di Gregorio and Shane, 2003).

Nevertheless, supportive governmental policies and incentives and strong university-industry linkages are important conditions for an entrepreneurial university. This is clear from the necessary conditions for a successful entrepreneurial university described in Etzkowitz et al., (2006; summarised in Zhou and Peng, 2008), which include both internal and external factors: (i) an excellent undergraduate, graduate and post-graduate education system; (ii) strong research capabilities; (iii) a well-developed technology transfer function; (iv) academic competencies and initiatives that apply new knowledge where there is no pre-existing demands; (v) considerable levels of funding investment from both industry and government; (vi) and favourable university-industry-government affinities.

A leading criticism of the Triple Helix model is that it fails to capture the unique characteristics of national (Shinn, 2002; Balzat and Hanusch, 2004) and regional (Cooke, 2005) contexts. As such, the model is ill-suited to providing a basis for researching, measuring and comparing different empirical cases (Mowery and Sampat, 2004), particularly when these cases are in different national and cultural contexts (Eun et al., 2006; cited in Cai, 2014). The model emerged from studies based in the developed world and there are those that have called for alternative theories for developing world countries (Eun et al., 2006; Zawislak and Dalmarco, 2011). However, several studies have successfully utilised the model in a range of developing country settings (e.g. in Africa: Kirkland, 2008; Kruss, 2008; Nwagwu, 2008; in Asia: Datta and Saad, 2008; Malairaja and Zawdie, 2008; and in Latin America: Etzkowitz et al., 2005; Mello and Rocha, 2004; Saenz, 2008). Furthermore, the concept's founding authors –

Etzkowitz and Leydesdorff – and their followers have acknowledged the differences between Western and non-Western countries (Cai, 2014). Therefore, whilst one can conclude that the Triple Helix model can be applied to a developing country setting, researchers should be cautious in generalising the findings from a single empirical setting to other countries.

In acknowledgement of this perceived shortcoming, the model has been extended by some researchers to include these further considerations of national and cultural identity. The Quadruple Helix (refer Carayannis and Campbell, 2009) adds the dimension of ‘media-based and culture-based public’, under the premise that the culture and values of a given context, along with media mechanisms, will have an effect on the innovation setting. An alternative Quadruple Helix has been proposed by Leydesdorff and Sun (2009), whereby a local-global dimension is added to the original three to capture the significance of international co-authorship. Further still, a Quintuple Helix has been proposed (refer Carayannis and Campbell, 2010; 2011), which extends the authors’ prior conception of a Quadruple Helix to also include the ‘natural environment of society and economy’, which encompasses considerations such as natural resources, biodiversity, environmental protection and sustainable development. However, whilst researchers may wish to move beyond the three core sectors, this must be verified, both theoretically and methodologically, and will require substantive specification, the operationalisation of potentially relevant data, and the further development of relevant indicators (Leydesdorff and Sun, 2009). Without such a perspective, researchers are wise to not extend the model beyond the relatively simple case of three dimensions (Leydesdorff, 2012).

Considerations of culture and natural environment are not within the remit of this paper. The Triple Helix is, however, a useful concept as it helps to understand how the Brazilian entrepreneurial university model came into existence and continues to thrive. It is a product of both top-down initiatives from government and bottom-up initiatives from the universities, and is otherwise dependent on fruitful collaborations and interactions with industry actors. As such, the Triple Helix model is valuable in providing a framework with which to discuss the dynamics between industry and academia. As with several preceding studies (e.g. Goldfarb and Henrekson 2003; La Paz et al., 2010; Philpott et al., 2011), this is examined in consideration of both the top-down and bottom-up initiatives that have shaped the formation of the academic entrepreneurship landscape. The initiatives underpinning the Brazilian model will be discussed following a presentation of the study’s research design. The university-industry dynamic will largely be discussed in respect to each case study USO in a later section of the paper.

Research Design

The objectives of the research are twofold. First, to determine, theoretically and empirically, the resources that USOs receive under an emerging model of the entrepreneurial university. The literature emphasises that this will include both stock resources, such as technological assets, and those that support the development of useful capabilities. As such, these resources can be separated into the tangible and intangible.

This resource-based view is combined with Vohora et al.'s (2004) stage-gate approach, so as to ascertain not only the mechanisms that are utilised by USOs but at which stage in the firm's development these prove most valuable. The framework from Vohora et al. (2004) is supportive in offering stages of development in a USO's formative years and critical junctures that it must overcome as it progresses. A firm's needs are different at each stage of development and it can only transition to the next stage once it has acquired the requisite resources and competencies. In many cases, specific university initiatives align well with particular critical junctures from the Vohora et al. (2004) framework.

The categorisation of initiatives in this manner builds towards a theoretical taxonomy of resources under which the components of the emerging entrepreneurial university can be classified. As a starting point, the four resource types offered by Djokovic and Souitaris (2008) – technological, human, social and financial – were useful. However, following some early documentary research and three pilot interviews with the management of the COPPE-UFRJ incubator and science park, it became apparent that these categories did not sufficiently encompass the full extent of the university's initiatives. Furthermore, there was an opportunity to separate out some of Djokovic and Souitaris' (2008) categories to add clarification. For example, classifying 'human resources' as the provision of personnel to the USO, whilst 'organisational resources' refers to the skills and competence training delivered to company personnel and, of course, the entrepreneur(s). Thus, the following types of resources are described through the empirical cases that follow:

Tangible resources

- Financial resources: may include direct financial investment from the university or support in connecting the USO with private investors or governmental funding bodies;
- Physical resources: the provision of physical infrastructure, which is typically shared with other USOs;
- Technical resources: use of university laboratories, equipment, machinery and instruments;

- Technological resources: utilisation of university-owned intellectual property and/or technological assets.

Intangible resources

- Human resources: access to/provision of university-based expertise and personnel;
- Organisational resources: skills development of personnel through training, consultancy and mentoring initiatives;
- Reputational resources: where the university provides the USO with reputational legitimacy and credibility, either through directed initiatives or simply by association;
- Social resources: may involve supporting the USO in developing industry contacts or otherwise engaging the company in the university's own network of industry partners, as well as connecting the firm with appropriate governmental and industry bodies.

The second objective of the study is to consider the broader implications that the emerging model of the entrepreneurial university holds for Brazil and other developing countries. The historical context – particularly with regards to the Triple Helix of actors at the core of the Brazilian entrepreneurial university model – is discussed in the subsequent section of the paper. Upon presenting the completed model, as derived from the empirics of the study, these broader implications will be discussed.

The study was conducted in a manner consistent with the general stages of case study research outlined in Miguel (2007; refer Figure 7). A multiple case study approach was adopted to explore several entrepreneurial universities within their real-life context. Such an approach is supportive of an investigation of a phenomenon in which the boundaries between said phenomenon and its context are unclear, complex and underexplored (Yin, 2003). Etzkowitz and de Mello (2004) state that the study of an entrepreneurial university is considered both a normative and an analytical pursuit in developing countries, where performance of the entrepreneurial endeavours will vary considerably. A multiple case study approach is therefore more appropriate than a single case study. Observation and analysis can be conducted in several settings, and findings can be verified and contrasted across cases (Eisenhardt, 1989; Yin, 2003). Such activities are central to theory building: the forming of theoretical constructs and/or propositions from empirical case study evidence (Eisenhardt, 1989). This is important given the research objectives of the paper.

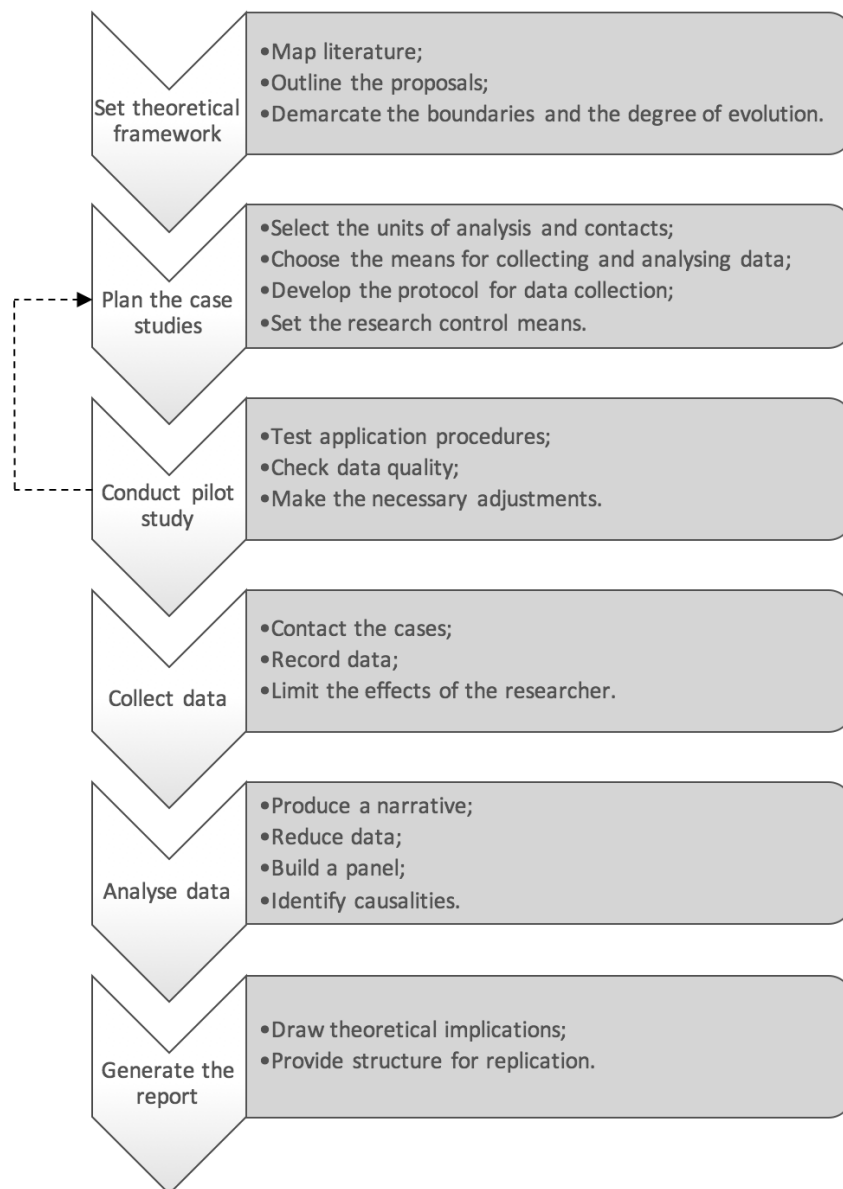


Figure 7: General stages of a case study (translated from Miguel, 2007)

The research is part of a broader project examining the transformation of a national and sectoral innovation system in Brazil (the latter of which is the Brazilian oil industry). Interviews with six groups of actors were conducted: small and medium-sized enterprises (SMEs); the management of university science parks and business incubators; MNEs (Brazilian oil champion, Petrobras, and international petroleum suppliers operating in Brazil); academic experts (within energy economics and petroleum engineering); governmental bodies (regulatory and funding organisations); and non-government industry organisations. Whilst the former two groups of actors are referenced most often in the forthcoming discussion, the changing role of universities in the country was discussed with each interviewee and these conversations have too informed the narrative of the paper. This has been supplemented with

a considerable degree of documentary research, both prior to, and following, the interview process.

Although locations in Brazil were selected in consideration of all of the aforementioned groups of actors, it was found that the siting of entrepreneurial universities (and attached science parks and incubators) went hand-in-hand with the presence of innovative domestic SMEs and petroleum MNEs. This is referred to in the literature as ‘purposive, non-probability sampling’, whereby research subjects are selected so as to reflect particular features of, or groups within, a population (Ritchie et al., 2003). Four cities were visited as part of the broader study, within which three universities were selected: the Federal University of Rio de Janeiro (UFRJ), the University of Campinas (UNICAMP) and the University of São Paulo (USP). However, it is worth noting that considerably more data was collected at UFRJ, as Rio de Janeiro is the country’s petroleum industry hub and therefore offered many more research subjects. Interviews were held with the managers of these universities involved in the entrepreneurial facets of operations (be it technology transfer, the creation of spin-offs, the management of the campus business incubator/science park, etc.), as well as the beneficiaries of such initiatives (i.e. incubated/science park resident SMEs).

Semi-structured interviews were selected as the primary data source, which have proven effective in preceding studies of entrepreneurial universities (e.g. Clark, 1998; Taylor and Thorpe, 2004; Matlay 2008; Philpott et al., 2011). The approach supports the gathering of detailed contextual information, granting the subjects flexibility in their responses, whilst also structuring the interviews in a way that ensures the key areas for discussion are addressed. Documentary research was collected from both internal sources (university reports and website information) and external sources (the extant literature and publications from organisations associated with Higher Education, technology transfer and entrepreneurship). Documentary sources were important in guiding the lines of investigation and research focus of the study and in substantiating and enriching the interview findings. With the exception of three pilot interviews with managers at UFRJ (conducted in May 2013), face-to face interviews were conducted during two month-long research periods in April 2014 and May 2015.

Data analysis was conducted in accordance with several techniques suggested by Miles and Huberman (1994). A database of the interview data and supporting documentary information was created in Microsoft Excel. This was coded with respect to emergent themes (e.g. ‘resource endowment’) and subjects were grouped in accordance with their role in the innovation system (i.e. incubated firm, incubator management, etc.). Analytical tables were created to support comparison and verification both across and within cases. Patterns were identified in the data

as part of an iterative process, leading to the extraction of conceptual insights as the study progressed.

Further details of the research practices and methodological choices made in this study can be found in Chapter 1 of this thesis.

Table 3 offers an overview of the three case study universities, each of which will be discussed further in the subsequent section.

Table 3: Case study universities

	UFRJ	USP	UNICAMP
<i>Founded</i>	1920	1934	1966
<i>National ranking*</i>	3rd	1st	2nd
<i>Type of institution</i>	Broad-based	Broad-based (biological sciences, exact sciences, humanities)	Technical (exact sciences, human sciences, biological sciences, technologies); research-focussed
<i>Campuses</i>	Rio de Janeiro, Angra dos Reis, Duque de Caxias, Itaperuna, Macaé, Nova Iguaçu, Paracambi, Piraí, São Gonçalo, Três Rios and Volta Redonda in Rio de Janeiro state	São Paulo (4), Bauru, Lorena, Piracicaba, Pirassununga, Ribeirão Preto and São Carlos (2) in São Paulo state	Campinas, Limeira, Piracicaba and Paulínia in São Paulo state
<i>Budget</i>	BRL\$3bn in 2013 (c. US\$0.9bn)	BRL\$5bn in 2014 (c. US\$1.5bn)	BRL\$2.3bn in 2016 (c. US\$0.7bn)
<i>Academic structure</i>	29 teaching and research units; 179 undergraduate courses; 178 graduate programmes (as of 2013)	42 teaching and research units; 300 undergraduate courses; 222 graduate programmes (as of 2015)	24 teaching and research units; 66 undergraduate courses; 153 graduate programmes (as of 2015)
<i>Academic output</i>	4,333 published articles (as of 2013)	17,282 published works in ISI (as of 2015)	3,192 indexed articles; 78 patents (as of 2015)

<i>Entrepreneurial structure</i>	Innovation agency; incubator; science park	Innovation agency; incubator (Cietec); science park (Supera)	Innovation agency; incubator (Incamp); science park
<i>Students and faculty</i>	56,000 undergraduate students; 11,500 graduate students 3,800 academic staff; 9,400 administrative staff (as of 2013)	59,000 undergraduate students; 30,000 graduate students 6,000 academic staff; 17,000 administrative/technical staff (as of 2015)	18,500 undergraduate students; 16,000 graduate students 1,800 academic staff; 8,500 administrative staff (as of 2015)
Note: rankings from QS (2015); also refer UFRJ (2013; 2016), UNICAMP (2015; 2016a) and USP (2015).			

Contextual Considerations

This section will first outline the history of the Brazilian university system, which is notable for the involvement of all three Triple Helix spheres in its development. This will be followed by a brief discussion of the current funding landscape for innovation in Brazil, which includes enhanced opportunities for those firms and university faculties engaged with the national petroleum industry.

Academic Entrepreneurship in Brazil

Brazil's history with universities is less than a hundred years old. The first university was created by the Federal Government in Rio de Janeiro in 1920 (UFRJ), followed by the University of São Paulo (USP) in 1934. The 1950s brought about intensive industrialisation, including the creation of national industry champions (such as Petrobras), that emerged from the import substitution policies enacted by the government. During this time, the rate of creation of universities (public and private) increased significantly and their role changed to include the training of human resources at the graduate level. This transformation is shown in Table 4 below.

The 'lost decade' of the 1980s, which saw huge levels of foreign debt and hyperinflation, led both industry and academia into crisis (Mello et al., 2011). However, the following decade saw profound changes in Brazil's economic structure: a significant increase in foreign investment, the privatisation of national industry champions (including Petrobras), and the modernisation of the country's leading companies. The role of universities increased to encompass the specialised training of human resources and introduction of apprenticeship initiatives.

Table 4: The process of industrialisation and university functions (adapted from Maculan, 1996; cited in Mello et al., 2011)

	Features of industrialisation	University functions
1920-1950	Heterogeneous industrialisation, with offshore technology incorporated in imported equipment, and the immigration of foreign technicians.	Few institutions of higher education (schools of engineering).
1950-1970	Import substitution industrialisation, with the creation of subsidiary companies for production by MNEs and state-owned companies in primary and public services sectors.	Training of human resources (engineering) as part of the process of industrialisation.
1970-1990	Diversification of the industrial base. Leading edge industries based on endogenous technology, and an increasing number of Brazilian employees at the managerial levels of MNEs.	Training of specialised human resources and research scientists for the apprenticeship process.
1990-Present	Industrial specialisation supported through sectoral funding. Increased interface between public and private STI activities.	Technology transfer and, later, the creation of new ventures and housing of such ventures in university incubators and science parks.

In the 1990s and 2000s, the government sought to enhance the competitiveness of Brazilian companies, which demanded both new technologies and specialised training from universities. In turn, the leading universities introduced TTOs, science parks and incubators to address their desire to commercialise research outputs.

Despite Brazil's continuing problem with a poor standard of basic education (e.g. an adult illiteracy rate of around ten per cent; Unicef, 2013), the country now has one of the leading university systems in the developing world, with a particular strength in graduate studies: 30,000 Masters and 10,000 PhDs per year, from 92 public and 86 private universities. These universities contribute close to two per cent of the global academic paper output (Sennes, 2009).

Brazil also has a strong history of university-based incubators over the last thirty years. The necessary conditions emerged in the 1980s, following the end of the military regime and the

country's return to democracy. The commencement of academic entrepreneurship in the country is perceived as a survival strategy in response to a decline in research funding in the early 1980s (Etzkowitz, 2015). The incubator model was imported from the United States as a means of commercialising research outputs (Etzkowitz et al., 2005) and was driven as a bottom-up process (Etzkowitz, 2008), with universities playing the pivotal role. That said, it also benefitted greatly from alliances with key government and industry actors (Almeida, 2005; Chandra, 2007).

The first incubator was established in 1986 in the state of São Paulo, followed by a second later that year in Santa Catarina (within the Federal University, UFSC). These incubators supported firms in traditional sectors, such as consumer goods and agriculture. This model originally emerged as an alternative to science parks, as they required fewer resources and could be managed by state governments (Almeida et al., 2011). Within ten years, the number of incubators had risen to forty (Akçomak, 2011). Most of these were located in either a university or research institute, and 80 per cent of the tenants therein were spin-offs from academia or other companies (Lalkaka and Bishop, 1996). Universities were the leading proponents of incubators at a time when incubation was not a recognised tool for supporting entrepreneurial endeavours (Akçomak, 2011). Government had only a modest role at this stage, with universities taking the lead (Etzkowitz et al., 2005), acting as the “key catalyst and facilitator” (Chandra, 2007).

By the early-1990s, incubators were often constrained by poor relations with academics, inadequate business support services and substandard physical infrastructure (Akçomak, 2011). The companies themselves were inhibited by bureaucracy and insufficient funding for riskier ventures (Akçomak, 2011; Chandra and Fealey, 2009): constraints that are present to this day. To address the constraints of the incubator sector, several government and non-government organisations (such as the Ministry of Science and Technology (MCT) and governmental funding agency, FINEP (Financier of Studies and Projects), and non-governmental industry body, SEBRAE – Brazilian Support Service for Micro and Small Enterprises) began to play a more active role in the incubator system (Chandra, 2007; Etzkowitz et al., 2005), providing further business support and funding where needed.

Universities remained the driving force behind new incubators, although the government (at state and federal level) continued to support these efforts, along with industry groups and regional associations (Almeida, 2005; Etzkowitz et al., 2005). Chandra and Fealey (2009) offer the example of the Cietec incubator, created in 1998 and located on the USP campus. This was the result of a partnership between the university, three national government bodies (including MCT and FINEP), two state government bodies, two public research institutes and one non-

government organisation (SEBRAE). The incubator sector continued to thrive despite the lack of a national strategy (Akçomak, 2011), which created a flexible environment whereby different incubator models with different aims could emerge (Etzkowitz et al., 2005). Together with the aforementioned initiatives, this led to a rapid increase in the number of incubators. Between 1995 and 1997, thirty-three new incubators were established (outnumbering the cumulative total that had been created prior to that period; Akçomak, 2011). By 2003, there were 1000 incubated firms in over 150 incubators in Brazil, together employing 15,000 people (Almeida, 2005).

Triple Helix actors continued to work together in support of incubators: an important arrangement to this day. The government's main drivers were technology development and socio-economic betterment (Chandra and Fealey, 2009). Whilst the universities shared these objectives, they also wished to foster an entrepreneurial culture and supportive environment in Brazil (Akçomak, 2011). The synergy between these objectives led to several government initiatives in support of entrepreneurship.

The 'Innovation Law' was passed in 2005, aimed at promoting the transfer of knowledge and science from universities and public research institutes to R&D efforts in the private sector. The law enacted the requirement of all federal universities to establish a TTO, permitted the sharing of physical and human resources between universities and firms, and allowed academics to leave the university system to establish a company, with the option to return to academia remaining open to them for three years.

This was supplemented with government subsidies through several funding bodies, most notable of which is FINEP, with a focus on increasing innovative activities in Brazilian companies (particularly SMEs). For the first time, firms could receive funding directly from public grants and subvention. Many of these initiatives – particularly sectoral funds for core industries (electricity, power generation, telecommunications, mining and petroleum, amongst others) – were directed to university-firm collaborative projects, which further strengthened industry-academia linkages. This was the case with FINEP's (recently discontinued) CT-Petro fund, which for thirteen years was the leading source of financial support for innovation in the petroleum industry.

There are now over 400 incubators in Brazil, across 25 states, which are home to over 8,000 companies. The survival rates for incubated firms is 80 per cent, compared with 30 per cent for non-incubated firms (Portal Brasil, 2012). The incubation sector is a highly evolved network of actors, including a multitude of government (at federal, state and local levels) and non-government organisations (Chandra and Fealey, 2009), with the majority of incubators still

linked to universities. Akçomak (2011) highlights this in comparing the features of Brazil's incubator sector with that of three other developing (and 'emerging') economies – Turkey, India and China – as well as the United States. Surprisingly, the incubator approach in Brazil has most in common with that of the United States, given its primary focus on technology transfer, fostering entrepreneurship and economic development; emergence from a bottom-up process; funding from mixed sources (i.e. industry, government and academia); and strong university management (Akçomak, 2011; AL-Mubarak et al., 2014; Chandra and Fealey, 2009).

Brazil has long been a leader in the creation of 'virtual' or 'without-walls' incubators (Scaramuzzi, 2002), whereby typical business support services are provided online to the incubated company but a physical infrastructure is not. University incubators offer entrepreneurship education modules at the graduate studies level, thereby encouraging new business creation prior to a student completing their studies. For some students, incubation is the next logical step after entrepreneurship education: offering co-located resources and capabilities to support a new venture (Chandra, 2007).

Due to the nature of how the Brazilian academic entrepreneurship model emerged – and particularly the incubator movement – it was the focus of several notable papers from Triple Helix researchers in the mid-2000s (refer Almeida, 2005; Etzkowitz, 2002a; 2002b; 2003; 2008; Etzkowitz and Mello, 2004; Etzkowitz et al., 2005; Viale and Etzkowitz, 2005). Etzkowitz (2008) asserts that it was the involvement of these three institutional spheres that made the incubator movement spread more broadly across the country. The incubator movement was utilised to reinforce linkages between Triple Helix actors and increase the academic sector's role in the country's socioeconomic development (Almeida, 2005; Etzkowitz and Mello, 2004). Etzkowitz and Mello (2004) suggest that this is indicative of a broader transition in Brazil from a government-led innovation system to a non-linear system of Triple Helix actors, including the 'hybridisation' of institutions across spheres (such as the aforementioned government-industry body FINEP; Etzkowitz, 2003). The government adapted its role during this time, acting not only as a regulator but also a public entrepreneur and venture capitalist (Etzkowitz, 2003). The incubator sector has now grown well beyond its academic origins, and has developed its own networks and organisations (Etzkowitz and Mello, 2004; Viale and Etzkowitz, 2005).

As already noted, in its early stages in Brazil, the incubator model differed from its high-tech US origins so as to address the country's socioeconomic problems (e.g. the Popular Cooperatives; Etzkowitz et al., 2005; Viale and Etzkowitz, 2005). Etzkowitz et al., (2005) asserted that this reconfiguration was a reflection of Brazil's science and technology policy

goals at the time. Over the last ten years, however, Brazilian entrepreneurial universities have increasingly focussed on high-technology endeavours, whilst maintaining a pursuit of knowledge-based socioeconomic development. This will be examined further in discussion of the case studies.

Innovation Funding in Brazilian Petroleum

As the companies interviewed for this study provide products and services for the oil and gas industry, (and one of the universities visited was UFRJ – an important innovation hub for the industry), there are several sector-specific policy interventions that will be discussed briefly here. For a comprehensive discussion of these policies, refer to Chapter 2 of this thesis.

One policy that is particularly of note – referred to hereafter as ‘the 1% Regulation’ – arrived following the privatisation of Brazil’s oil industry, which broke the forty-year legal monopoly of Petrobras. In that same year, a new industry regulatory agency, ANP (National Agency of Petroleum), was created. It was ANP that introduced the 1% Regulation (Federal Law No. 9.478/1997, Article 8), which obligates all operators in Brazil’s high-yielding oil fields to retain 1 per cent of the gross revenue from exploration and production activities in those fields. The funds are used by the operator to finance R&D activities in Brazil. At least fifty per cent of this must be used for the hiring of accredited Brazilian universities and public research institutes for R&D projects (including the construction of laboratories and purchase of equipment/materials). The remaining funds can be either invested internally (on R&D activities in the Brazilian premises of the operator), or used to hire Brazilian companies for R&D projects. The regulation raised \$3 billion between 1998 and 2014 for R&D activities in Brazil. However, with the acceleration of pre-salt production on the horizon, the regulation is expected to raise an estimated US\$30 billion over the next ten years (ANP, 2014).

The Brazilian government also greatly increased R&D investment in the petroleum industry during this time (along with other core industries, such as agriculture, health and telecommunications), primarily delivered through BNDES (National Bank for Economic and Social Development) and FINEP, as well as regional states’ own funding agencies (e.g. FAPERJ in Rio de Janeiro, FAPESP in São Paulo). In 1999, several specialised sectoral funds for science and technology were created (focussed on the aforementioned core national industries), administered by FINEP. Further petroleum-specific funding was made available on both a subvention and loan basis (such as the CT-Petro and, more recently, Inova Petro funds). This can be seen as Brazil’s first step in linking governmental industry goals to science and technology activities in academia.

National spending on both science and technology and R&D increased by more than five-fold in the resulting thirteen years (2000-2013; MCT, 2015). It is important to note that the majority of funding during this time has been directed to either universities or university-firm collaborations. As such, these initiatives have failed to adequately support domestic firms in the industry (refer Chapter 2).

Analysis

The following discussion is framed through Vohora et al.'s (2004) five-stage framework and will also make reference to the authors' four critical junctions that occur at the intersection between two stages. Although many of the initiatives here prove beneficial across several stages of a company's life, they are discussed within the context of the stage in which they make the greatest difference to the entrepreneur/firm's development, particularly when this supports overcoming a certain critical juncture.

Research

In this first stage, an important mind-set change must occur in the entrepreneur. To date, they will have spent their academic life focussed on publishing their research in pursuit of recognition from the scientific community (i.e. the 'publish or perish' mentality; Vohora et al., 2004). To overcome the 'opportunity recognition' critical juncture, the researcher must acknowledge the potential for commercialisation their work holds, and further their own potential as an entrepreneur. Several supportive mechanisms were identified in the case study universities in this regard.

First, the students are exposed to the possibility of entrepreneurship at the undergraduate level. Entrepreneurship education is present to varying degrees across the sample universities. USP offers elective courses to its students in Innovation and Entrepreneurship, delivered through the university's Innovation Agency. A similar approach is adopted by UNICAMP, where the courses are aimed at "raising awareness about the world of entrepreneurship and innovation, [...] making entrepreneurship a real career option" (UNICAMP, 2016b). For students within UFRJ's engineering school, COPPE, comparable courses are part of the mandatory curriculum for students. UFRJ's neighbouring university, PUC-Rio, has extended this further so that every undergraduate student, across all faculties, must take a basic course in entrepreneurship (Etzkowitz, 2008). Interventions such as these open the student's mind to the possibilities of business ownership and give them the basic skills and understanding from which they can begin to formulate ideas.

This is particularly important in a country such as Brazil, for two reasons. First, for at least some students, it will reduce some of the mystery behind entrepreneurship, which is regarded as an extremely risky venture in Brazil, as several interviewees attested. This was first discussed with Cíntia Soares, who is the Business Development Director of Oil Finder: a resident company in the COPPE incubator. “People are always concerned about [...] finding a job in a large company [or] working for the government. [...] Some of them [are] trying to work for the government because they would have stability and it would be an easier life to live. [...] Everybody called me crazy” (Cíntia Soares, Oil Finder). This sentiment was echoed by three other interviewees. In discussing the challenges Brazil faces in generating higher rates of entrepreneurship, Ms. Soares stated: “more than anything, it is culture. It is knowing that being an entrepreneur [...] can be a very good way of making money, generating jobs and contributing to society” (Cíntia Soares, Oil Finder).

Secondly, in contrast to many developed countries, business management is not taught as part of the secondary school curriculum in Brazil. Thus, the broader implications of entrepreneurship education initiatives in higher education is that the student will carry these skills and this ‘entrepreneurial awareness’ with them into their working lives, regardless of whether the student engage in the spin-off process.

A further initiative, which again supports the development of business management skills and entrepreneurial awareness, is the hiring of students in incubated USOs. This was a common practice at each of the incubators visited. However, at one company in particular, the benefits of this were most evident. Technomar is a high-technology ocean engineering company that is incubated at USP. The company’s director and founder, Fabiano Rampazzo, stated that one of the key benefits of the firm’s incubation was access to expertise, including the hiring of many PhD and Masters students from the adjoining laboratory on a part-time basis. Although not underwritten in the incubation contract, Mr. Rampazzo described the hiring of students as a “rule” with which they must comply. Hiring students is strongly encouraged by both the university and the incubator. This benefits the company in providing lower-cost personnel that are trained in the use of the sophisticated equipment. For the university, this meets a goal of their own: to develop an entrepreneurial aspiration in their students during their period of study. These students gain employment experience, expanding their skills in the laboratory, but can also appreciate first-hand the possibilities of entrepreneurship. This was discussed with Prof. Kazuo Nishimoto, a co-founder of the company and practicing professor at USP:

“Some of the students have an interest in having their own company [...] and would like to use [...] a product developed here. [...] This is motivation for them, so why not create this behaviour for them? [...] We have several [prize-winning] developments in [...]

engineering science but on the other side we [...] create people who are motivated to [be entrepreneurs]” (Kazuo Nishimoto, USP).

Opportunity Framing

The objective here is for the prospective entrepreneur to determine the commercial prospects of their technology, so as to identify potential applications and markets away from the laboratory (Vohora et al., 2004). A university’s TTO can play an important role here. The presence of a TTO at all public universities in Brazil has been mandatory since the enactment of the Innovation Law in 2005. However, in the three case study universities, it was apparent that the typical model of a TTO had been considerably extended. UFRJ replaced its TTO with the Innovation Agency (Agência UFRJ de Inovação) in 2007, so as to reflect the broader remit of activities. UNICAMP and USP have followed suit, establishing their own Innovation Agencies. This role further includes management of the university’s science park and incubator; attracting public investment from the state and sponsored research from industry; encouraging innovation and entrepreneurship from its academics; ‘social innovation’ (i.e. the development of new solutions to stimulate social change); and promoting a culture of entrepreneurship both within the university and the respective region.

The UFRJ Innovation Agency provides specific support at the Opportunity Framing stage in the form of technical consulting services and access to detailed dossiers of technological information. The university accrues this insight into market opportunities through collaborative partnerships with industry and sponsored research projects as part of its broader remit. The Innovation Agency works with the entrepreneur to align laboratory innovations with potential markets and their needs, identifying where adaptations to the technology are required to better meet these needs.

At COPPE-UFRJ, this is supplemented by the COPPE IDEA programme (founded in 2010), which shares a similar remit to UFRJ’s Innovation Agency: support the commercialisation of research projects from thirty laboratories at COPPE; assist the school’s academics in establishing start-up companies; deliver courses in promoting entrepreneurial opportunities; support technology transfer to SMEs; and liaise with large companies to promote technical cooperation in areas of expertise (Estefen, 2011). The organisation recognises the need to increase the number of domestic innovative companies in Brazil and is driven to creating a ‘critical mass’ of entrepreneurs from the university (COPPE-UFRJ, 2015a). At this stage of the entrepreneur’s development, it offers support in much of the same way as the Innovation Agency: assisting the entrepreneur in creating a company (including the possibility of incubation) and shaping ideas for the marketplace. There are similar school-specific programmes elsewhere in UFRJ, as well as at UNICAMP and USP.

Opportunity framing is also encouraged through student and faculty competitions. UNICAMP's Innovation Agency, for example, runs a yearly competition to support the creation of new ventures from the university's proprietary technologies. Applicants form a team of three to five people and have a choice of technologies from the university's database, although the agency also promotes certain technologies regarded as having particular commercial potential. Detailed information about the chosen technology is disclosed to the team. Support is offered during the three-month process through workshops, lectures and mentoring. Teams must develop business plans and scrutinise the technology for its potential commercial applications. The winning team is awarded a grant from the university to then pursue the endeavour further. Similar competitions are held by UFRJ and USP.

The critical juncture here is entrepreneurial commitment, where entrepreneurs are often faced with four key barriers (Vohora et al., 2004):

- a lack of business experience;
- a lack of self-awareness from the entrepreneur as to their personal limitations;
- a lack of role models; and
- the difficulty in identifying, accessing and acquiring the services of a surrogate entrepreneur.

Regarding the first point, entrepreneurship education continues to be available from both the university and the incubator. In the case of the latter, this is understandably designed specifically towards business ownership skills and is tailored to the company in accordance with the current stage of development and recognised weaknesses in required competencies. These weaknesses often stem from the entrepreneur's background as an academic, especially in cases where they have not previously undertaken entrepreneurship education, as was underlined by Lucimar Dantas, who is the Operations Manager of COPPE-UFRJ's incubator:

“Our owners, entrepreneurs, are scientists [...] who [...] are very focussed [on] the technology. So, our role is [to] open their minds to other points, to the business. Not only technology. [Technology] is important, a major point, but if the other [factors] are not [...] in their minds [they] have problems with the business” (Lucimar Dantas, Incubadora de Empresas COPPE/UFRJ).

The role of the incubator at this stage of development was discussed with the founder of each case study USO, many of whom spoke with great appreciation for the provided service offering in shaping both the firm and the entrepreneur at this early stage. As the leader of an incubated

firm with a background in business management rather than engineering, Cíntia Soares of Oil Finder was able to offer a unique perspective:

“This incubator [...] receives a lot of start-ups based on technologies developed in the university. [...] We are talking about students and professors: people who are not connected to the market. [...] So, these people, these entrepreneurs, when they come to the incubator, they do not have a clue about how to develop a business, how to [run] a company. [...] I think the incubator plays a very big role in switching this mind[set]” (Cíntia Soares, Oil Finder).

Identification of these weaknesses can be hindered by a lack of self-awareness from the entrepreneur as to their personal limitations (Vohora et al. (2004) but the incubator also endeavours to address this:

“[They emphasise a ...] message [...] to the entrepreneurs that ‘you may be a terrific professor, you may be an excellent [scientist] but [...] that does not mean you are going to be an excellent businessman. And you have a long way to [go], a lot of things to learn, and [we are] going to support you [in] that’. And they do” (Cíntia Soares, Oil Finder).

The lack of role models is addressed at all three universities through mentoring programmes, delivered through the Innovation Agency and the incubator. This often involves utilising alumni and founders of graduated firms to offer insights into their market experiences. Mentoring focuses on building a network of knowledge and experience from which entrepreneurs can benefit.

The scarcity of surrogate entrepreneurs (and further, venture capital) is also indirectly supported by the respective incubators, which assist entrepreneurs in preparing the necessary documentation with which to apply for private (and public funding agency) investment.

Entrepreneurial commitment from academics is further supported by the Innovation Law, insofar as it permits academics to leave the university system in order to start a new venture, whilst offering the reassurance that they may return to academia in the future. Given the negative perception of entrepreneurship as a career option in Brazil, this is particularly important. The founders of two companies – Prof Nishimoto of Technomar and Josias Silva, founder of Petrec (incubated at the COPPE-UFRJ incubator) – had done exactly this, with the former now maintaining teaching and research responsibilities alongside those held with the company.

Pre-organisation

At this stage, the entrepreneur has framed the commercial opportunity, has committed to pursuing it, and must now develop the necessary strategic plans (Vohora et al., 2004). The emphasis here is on resources: ascertaining the existing holding of resources and competences, identifying those that will be required in the future, and establishing when and how to obtain them. Vohora et al. (2004) describe this as the steepest learning curve for the academic entrepreneur, particularly where the entrepreneur has no previous commercial experience and few existing relationships with potential clients and investors.

With regards to investment, universities provide significant assistance in securing financial resources. While public universities are not permitted to financially support private enterprises (as underwritten by Brazilian law), they do provide services to assist firms in obtaining these resources from both public and private funds. For example, and as noted above, the COPPE incubator provides support services to prepare firms in seeking venture investment and public funds. COPPE is also notably well connected to national funding bodies, such as FINEP and BNDES, as well as the regional funding organisation FAPERJ. The incubator has a strong relationship with non-governmental industry bodies such as ONIP (National Organisation of the Petroleum Industry) and SEBRAE, who themselves are well connected to these funding sources. Representatives of ONIP and SEBRAE will often visit the incubator and deliver seminars on how incubated firms can attract funding and request further business support assistance.

In addition to the entrepreneurship education offered by the three case study universities, each incubator offers training in business management skills and consultancy services in key areas. Ms. Soares (Oil Finder) offered an overview of those available at the COPPE-UFRJ incubator:

“We have meetings and we have courses. We have a lot of training in sales, in finance. We have what they call ‘advisories’. [...] Now we are established we do not take a lot of advantage of that but in the beginning it was very important. [...] Consult[ing], complex sales processes, or advising financial reports and managing, monitoring, accounting issues, or visiting from investors. So they provide a very good [level of] support to entrepreneurs” (Cíntia Soares, Oil Finder).

The advisory services offer all incubated companies a variety of organisational resources: marketing; communication and media relations; visual programming (i.e. creating the company’s visual identity and dissemination materials); finance (preparation of projections and financial controls, assistance with investment planning, and preparation for seeking venture investment); entrepreneurship (identifying areas of improvement in the entrepreneur’s

professional profile); accounting; and legal (COPPE-UFRJ, 2015b). The incubator's frequent meetings (scheduled fortnightly) provide a forum for the exchange of experience, knowledge and information between the companies (some of whom will have been incubated for a matter of months; others for several years). Monitoring of companies is maintained by the incubator: formally on an annual basis, as well as making advice available constantly throughout the incubation period (COPPE-UFRJ, 2015c).

The incubation period at all three universities is typically twenty four months. Within that, COPPE-UFRJ also offers a four-month long accelerator programme. This includes specific organisational and networking support, training and mentoring, with a view to getting the firm to market by the end of the acceleration period. This is part of a broader movement within Brazil, which, as with the incubator model, has been transported from the United States. Private accelerators were first established in Brazil in 2011 and are considerably more prevalent than university-based accelerators at present. The extent to which accelerator programmes such as this will capture the imagination of the country's public universities remains to be seen.

With regards to human resources, university incubators offer a unique opportunity to resident firms. The proximity of the host incubator to professors and students in specialised fields is cited as one of the main advantages by interviewees. For example, Daniel Camerini, whose company Ativatec is a resident of the COPPE incubator, said that one of leading opportunities "of being near the university is to have the students come to [work] for the company. [...] It is easier to get students to work in the company as they can work and study at the same time. [...] In the area of oil and gas and new technology, you can do a partnership with university laboratories and [support] the research with professors" (Daniel Camerini, Ativatec).

Josias Silva (Petrec) also noted this relationship as a key strength:

"We have a collaboration with the university. [...] The technology was created within the university, we pay for that, and we select some students or some professors here to support us. [...] Since I have worked for the university for more than twelve years, I have a lot of relationships with COPPE. [...] It is great for us because in the beginning of the process you do not have funds to sponsor people, machines, computers. [...] Besides [our staff] we have another nine [academic researchers] in the lab, working together. We have this synergy. Sometimes we ask them to do something for us and sometimes we do something for them. We have this relationship. [...] All of them are Masters or PhD [students]" (Josias Silva, Petrec).

Several firms interviewed were also benefitting greatly from access to the facilities and equipment of the parent university (i.e. technical resources). For example, Ms. Soares spoke

of the support Oil Finder received from both the incubator and the laboratory from which Oil Finder spun off:

“The university supports us not only with the business incubator but also with the access we have to human resources, supercomputers. [...] Today we are independent from the supercomputer at COPPE but in the beginning we used to use their machine. [...] A lot of simulations are very heavy so we had to use it. [COPPE] was very supportive also in this way” (Cíntia Soares, Oil Finder).

A similar case was found in Polinova, who are also incubated at COPPE-UFRJ and who specialise in exceptionally high-specification polymers and coatings (including nanotechnology applications). The company counts Petrobras and (global subsea technologies leader) FMC Technologies amongst its clients, yet employs only ten people. The company continues to exploit the parent laboratory from which it spun off as the fabricator for its products, thereby utilising world-leading technology that the vast majority of its competitors do not have access to and whose products are inferior.

Whilst in both cases these companies have financial agreements with the university for the use of these facilities, it nevertheless demonstrates that the university is highly supportive at this stage. Such support offers a strong competitive advantage at a time when the company is in its infancy.

The most interesting example of providing support through access to university facilities is Technomar. The company’s owners are all former students of the TPN laboratory, with the exception of Prof. Nishimoto. The laboratory was founded in 2002 in partnership with Petrobras and is particularly focussed on addressing the technical challenges faced by oil production in the pre-salt fields. The laboratory combines a physical model-testing tank with a highly-advanced computer-based simulation system, making it one of the leading research and testing facilities (quite possibly *the* leading facility) for offshore petroleum studies in the world. Technomar is very much a continuation of TPN’s expertise, as one might expect from a spin-off of a university laboratory. Interestingly, however, Technomar does not reside in USP’s incubator (Cietec) but rather in the TPN laboratory. This was discussed with Mr. Rampazzo: “we do not need to be there because we have the infrastructure [of TPN] that we have access [to] and, for ocean engineering, it is more appropriate to be here than [in Cietec]” (Fabiano Rampazzo, Technomar). As with the above two examples, the company has a cooperative agreement with the university for the use of the laboratory. This is an example of a small firm, with barely more than a dozen employees, having access to some of the world’s leading technology in their field.

There is little discussion of such a model in the literature but it been identified previously by Etzkowitz (2015), who referred to ‘the firm in a lab’: “a joint academic research group and business firm that produces research results, journal articles, and marketable products, at one and the same time in a common unit housed within the university”. Etzkowitz, in fact, draws on an example from Brazil’s Pontifical Catholic University of Rio do Sul, where a biotechnology hybrid company operates from a laboratory. The creation of such an enterprise in Brazil is possible due to the Innovation Law, which permits universities to sponsor academic-commercial hybrid organisations and allows a ‘confluence of interest’, whereas incubation in a laboratory would be discouraged in the United States due to conflict of interest concerns (Etzkowitz, 2013b). Such a model eliminates the need for duplicate facilities, whilst also addressing the ‘valley of death’ created when a separation is made too early between academic research and commercialisation due to strict conflict of interest rules (Etzkowitz, 2015). Etzkowitz describes “this recent development [as] the latest example of innovation at the interface of university-industry-government” (i.e. the Triple Helix).

The critical juncture here is credibility and therefore reputational resources are also of significant importance. Vohora et al. (2004) discuss the *credibility threshold* that companies must overcome so as to not constrain their ability to acquire key resources – particularly financial investment and human capital. The directors of several incubated and previously-incubated firms spoke of the credibility that their firm receives/received as a result of being incubated. For example, the founder of an incubated meteorology USO stated:

“When you are in [the] incubator, you carry the name ‘COPPE’ and ‘UFRJ’ when you are doing a presentation [...] for your services. [...] It is a symbol of quality, a symbol of innovation. It is very important to us” (Fabio Hochleitner, Aquamet).

Mr. Hochleitner’s comments are supported by the literature. Spin-offs are often considered in the context of their parent organisations and their reputation (Wright et al., 2007). Di Gregorio and Shane (2003) assert that USOs find it easier to attain resources for reasons of credibility. A university’s credibility, along with its support structure and network of industry and funding connections, aids entrepreneurs in developing industry contacts, improving their social capital and establishing relationships with financial providers (Delmar and Shane, 2003; Grimaldi and Grandi, 2005; Mian, 1996; Tötterman and Sten, 2005).

Re-orientation

By this stage, USOs have now gained the credibility and accessed the requisite resources to generate returns, with the entrepreneurs becoming viable business leaders. A process of ‘continuous repacking’ of resources is needed, so as to adapt the firm’s strategy and business

plans in accordance with both internal resource constraints and changes in the external environment (Vohora et al., 2004). This aligns with the notion of dynamic capabilities (Teece et al., 1997) outlined in the literature review above, which describes a cyclical process of identifying, acquiring and integrating resources and subsequently re-configuring them. These resources will include organisational capabilities, with which firms can coordinate productive activities and address the challenge of growing the business and generating increasing revenues in the future (Vohora et al., 2004). As such, the organisational resources delivered through the university incubators (training, consultancy services and mentoring programmes) are also of great importance at this stage.

A mindset change is necessary, which requires the business owner to become much more market-focussed: not an easy task when the entrepreneur in question has come from a background in academic research. This was discussed with Ms. Dantas at the COPPE-UFRJ incubator, who described the challenge both the entrepreneur and the incubator faces in achieving this mindset change:

“The major challenge is [the] market: look to the market and understand what the consumer wants. [...] The profile of our owners is [mostly] scientists: doctoral students that are developing this for the whole of their [...] professional life, so are very focussed on the technology. [...] The main challenge for us is to create another perspective: to look to the market, understand what they want. [...] Normally we have companies that are composed exclusively from technicians and scientists. [...] It is wonderful for the high-tech, to create innovative systems and solutions, but sometimes the solutions are not fit for the market” (Lucimar Dantas, Incubadora de Empresas COPPE/UFRJ).

The literature emphasises the need for USOs to change in response to other market actors (customers, collaborators, competitors, suppliers) and potential investors at this stage, thus placing an emphasis on addressing social liabilities and strengthening social capital (Vohora et al., 2004). The incubator environment and initiatives assist considerably in this social capital dynamic by creating networking and market opportunities with potential clients and collaborators. This is most pronounced at UFRJ, given the high concentration of oil and gas companies within the incubator and adjoining science park: an area of less than 0.5km². Roughly half of the incubated firms have products/services marketable to the oil and gas industry, whilst the park is home to the technology centres of eight of the world’s leading oil and gas companies (such as Schlumberger, Halliburton, Siemens, General Electric and BG Group), with Petrobras also located within walking distance.

Mauricio Guedes, the Director of the UFRJ science park, and his colleague Leonardo Melo, an employee of the park's Corporate Relations team, discussed the extent to which networking and collaboration are objectives of the incubator and science park, and the challenges faced in achieving this:

“The concept of the park is to be an open innovation platform, so we have to stimulate cooperation between the companies and the university, the companies and the suppliers, the companies and the competitors. That is the role of the park: [...] to be a meeting point. [...] The collaboration amongst the companies is [...] very important for us” (Mauricio Guedes, Parque Tecnológico).

“It is not enough to put a big company and a small company in the same place. [...] We have many actions to improve [interaction], to create bridges between these companies. We have work groups, we have workshops, seminars, formal meetings [for] presenting [what they] are working on. We are trying to [...] ask the big companies how are they challenged: technological challenge[s] and problems in some areas and to show these challenge[s] to the [...] small and medium companies and [...] our laboratories. [...] The main aim is to put specific [people] in the companies to work together, or not to work together but to meeting, in formal ways, even in informal ways” (Leonardo Melo, Parque Tecnológico).

“We are creating new ways, new formal ways of interaction between the park and the incubator. The incubator is part of the park from a conceptual point of view. [...] We strongly believe in the incubator [...] and the direction of COPPE. The incubator is connected to COPPE. [...] COPPE] want[s] to have a stronger and formal relation[ship] between the incubator and the park” (Mauricio Guedes, Parque Tecnológico).

The management of the science park employs a number of mechanisms in its pursuit of a collaborative and cohesive environment for innovation. As alluded to above, there are regular meetings with all the companies in the science park and incubator, where MNEs are encouraged to discuss the technical challenges they are facing and SMEs present their product/service offering. Mr. Camerini (Ativatec) described these meetings as not just a platform for showcasing his firm's capabilities but also an opportunity to gain new perspectives on their business. It is therefore an additional platform for the endowment of organisational resources:

“Sometimes when you are just working in your company with your partner you see only one thing, only one way of running the business. And here, with these meetings with other companies, we can discuss our business and have [other] opinions [...] and another kind of view on how [to] run the business. And they [ask] a lot of questions and [...]

help you to think about your business and see if it is going how you were wishing” (Daniel Camerini, Ativatec).

Several other informal mechanisms that support social capital were also observed at COPPE-UFRJ. Every company in the science park and incubator share a single restaurant, away from the rest of the campus. This has proven a useful forum for informal discussions between firms. A technology manager from one MNE (who requested anonymity) described how a multi-million US\$ value contract with one of the science park’s SMEs had been initiated by a conversation over lunch. More whimsically, various modern art pieces, including a collection of garishly coloured dolphins, have been placed around the science park in the hope they will be a conversation-starter between potential collaborators.

Opportunities for domestic firms are scarce in Brazilian petroleum – more so in the case of SMEs – as is discussed in Chapter 2 of this thesis. Despite this, several of the COPPE-incubated SMEs have worked with MNEs in the science park. Geovoxel is one such example, and the company’s Director, Louis-Martin Losier, was in little doubt about the role the science park had played in making this possible: “it was because of the proximity with [MNE-1]. We met with the general director of [MNE-1], who came here for a presentation. He liked the product and made a proposition” (Louis-Martin Losier, Geovoxel).

This collaborative environment is also apparent internally within the COPPE business incubator. Of the seven oil and gas USOs hosted in the incubator that were interviewed for this study, five had collaborated with at least one other incubated firm. These interviewees spoke of these collaborations with great enthusiasm and asserted their intention to increase the number of such partnerships in the future. For example:

“We are working with three companies in the incubator. [The incubator management] provoke this with [regular] meetings. [...] The proximity to the science park is also great for us because we have lots meetings there. [...] It is not easy but it is easier than if we were not here. With companies like Halliburton, Baker Hughes... for incubated firms the door is open” (Josias Silva, Petrec).

Undoubtedly, the opportunities for collaboration are increased under this industrially specialised environment. The state has played a significant part in this. The UFRJ science park, as it stands today, was shaped by the discovery of the pre-salt oil reserves and associated government interventions. The 1% Regulation provided a platform for large-scale investment in R&D in Brazil. The capital investment from government funding bodies, such as FINEP and BNDES, provided for much of the infrastructure of the science park and business incubator

(with the exception of the MNEs' own technology centres), as well as funding collaborative efforts between the universities and private enterprises.

However, the role of the university is absolutely pivotal. As asserted by the science park management, it is not enough to simply arrange these actors within close proximity and expect them to collaborate together. The business incubator and science park management teams have applied many mechanisms in order to stimulate interaction, both formal and informal, and declared their intention to improve these mechanisms in the future. While the incubator model was originally envisaged as an alternative to science parks (Almeida et al., 2011), the COPPE campus shows how the two can work in synergy: offering a platform for progression to incubated firms and generating a higher degree of collaboration than would be possible through a single model.

Market opportunities can also emerge from relationships between incubator/science park firms and the host university. The founders of Technomar discussed one such market opportunity. Several years ago, a global subsea technology MNE hired the TPN laboratory to conduct some testing and simulation work in preparation for an offshore petroleum installation. TPN subsequently hired Technomar to carry out some of this work, thereby creating a working relationship between the two firms at a time when Technomar had only a few employees. When asked if similar opportunities had resulted from this connection with the laboratory, Mr. Rampazzo replied:

“All these projects we have to date came to us; we did not go and look for them”.
[Interviewer: “So they came to you because of the reputation of the laboratory and university?”] “The first contracts, yes. This helped a lot” (Fabiano Rampazzo, Technomar).

Similarly, Louis-Martin Losier (Geovoxel) stated: “[COPPE] were approached by a big company to do some consulting and they called us to participate on those projects. So, for us, it was very good, this proximity with the university” (Louis-Martin Losier, Geovoxel).

COPPE has enjoyed a close relationship with Petrobras for over forty years: the science park is very much an attempt to foster similar collaborations between further companies and the university (as was affirmed in the interviews with the UFRJ science park management). As such, former students of COPPE who create USOs also benefit from this relationship and the proximity to Petrobras:

“[Petrobras] know about us because [we] worked on research and development projects with the university. Before opening the company, we were students and we worked with

Petrobras as university employees. [...] We opened a company to develop subsea robotics and they knew we have expertise in this area. [...] We [then] started to be recognised in [this] area” (Daniel Camerini, Ativatec).

The possibility of this kind of relationship – described by Mauricio Guedes (Director of the UFRJ science park) as an “umbilical relationship with the university” – is a key objective when incubating a firm. Lucimar Dantas (Operations Management of the COPPE-UFRJ incubator) described the selection process by which prospective incubated firms are selected: innovativeness of the technology; economic prospects; and the firm’s relationship with the university. In the case of the latter, this assures the university that a relationship with a laboratory is established and will likely continue to reap technology transfer opportunities as the company grows.

Sustainable Returns

At this stage, the company will have addressed earlier uncertainties and weaknesses, honed its business model, and emerged as a highly-focussed business, capable of achieving sufficient returns, and an established competitor in the marketplace (Vohora et al., 2004). For an incubated firm at UFRJ, UNICAMP or USP, as it grows and comes to the end of its incubation period, it will have the option of applying for residency in the adjoining science park. At UFRJ, for example, the science park’s multi-tenant buildings offer several of the benefits of the incubator: a shared physical space and infrastructure, lower costs, proximity to the university, and associated networking opportunities. For many firms, there will be a natural progression from the business incubator to the science park, which will particularly aid the company in upholding its relationships with the university and other firms. When interviewed in April 2014, Oil Finder were approaching the end of their incubation period, and the possibility of moving to the university’s science park was discussed with Cíntia Soares:

“When we [leave the incubator], we will lose many things. [...] We are thinking of moving to the [technology] park. [...] I think that this [would] lower the risk but it is also good to be here. We have many companies working for the oil and gas industry here in the park, so it is a very good environment to be [in]. [...] We have many visits from other countries as well – many associations or people who are trying to [network]” (Cíntia Soares, Oil Finder).

Another interview was held at a firm that had recently graduated from COPPE’s incubator and was now installed in UFRJ’s science park. The decision to remain within the university campus was discussed with the company’s director (who requested he and the firm be anonymised):

“You cannot put a price on the proximity to UFRJ and other technology companies, for both the image of the company and for the medium to long-term prospects of the company” (Anonymous, SME-1).

These benefits were also discussed with Ms. Dantas at the COPPE incubator:

“We have an intangible [...] factor here. [...] For these companies [to] stay in this land, in these buildings, is very strategic. [...] This is a real benefit that they look for. Of course, [...] the package of all the services we offer here is important for them [and ...] we [add] a [lot of] value in this point. But this intangible factor [...] is very important. [...] Many companies that are incubated here want to stay in the campus after graduating. [...] In 2012, [...] four companies graduated [from the incubator] and all these companies are [now] established in the [technology] park. [...] They are from the university, they are from some lab, so [to] stay here and continue [to be] connected to the lab is very strategic because this is the [...] place where they can create other products and other services and other solutions for the market. So I think this is very important.” (Lucimar Dantas, Incubadora de Empresas COPPE/UFRJ).

Acknowledging the benefits the science park offers domestic firms, and the technology transfer opportunities for the university in having innovative collaborators located nearby, UFRJ are to expand the science park in the coming few years. Innovation Tower – a project still in the early planning stages – will create enough office space to more than double the number of SMEs that can reside at the science park (from around forty to one hundred). The site will include two multi-tenant buildings, a 200-room hotel, shopping centre, restaurants and other services. The site will make it easier for international visitors to attend the park, which, whilst located close to the international airport, is a considerable distance from downtown Rio de Janeiro.

Summary

The purpose of this sub-section is to both summarise the key findings from the preceding discussion and to elucidate the broader implications. Figure 8 shows a summary of the resource endowments entrepreneurs (and potential entrepreneurs) and incubator and science park resident firms receive from the three case study universities, as structured in accordance with the Vohora et al. (2004) stage-gate process and this study's taxonomy of resources.

	Research	Opportunity Framing	Pre-organisation	Re-orientation	Sustainable Returns
Tangible	Financial resources	Grants for student start-ups			Technology park - physical workspace and shared infrastructure
		Liaison between firm and public funding bodies/venture capital investors			
		Assist in the preparation of documentation required to pursue public funding/venture capital			
		Promotion of available investment opportunities (public & venture capital)			
	Physical resources	Incubator - physical workspace and shared infrastructure			Technology park - physical workspace and shared infrastructure
Technical resources	Access to university laboratories, equipment, machinery and instruments				
	'Firm in a lab'				
Technological resources	Licensing opportunities				
	University-USO collaboration opportunities				
Intangible	Human resources	Access to expertise of university faculty			
		Hiring of students			
	Organisational resources	Student entrepreneurship education			
		Entrepreneurial awareness (e.g. incentivisation of student work experience in USOs)			
		Entrepreneurship competitions			
		Mentoring programmes			
		Technical consulting services			
		Business skills development training			
		Dissemination of technological/market information			
	Reputational resources	Accelerator programmes			
Entrepreneur reputation					
Firm reputation					
Social resources	Product reputation				
	Liaison between firm and governmental industry bodies (e.g. ANP) and industry intermediaries (e.g. ONIP, SEBRAE)				
	Promote networking, collaboration and market opportunities between actors (meetings, workshops, seminars)				
	Establish and maintain university-USO 'umbilical' relationships				
	Market opportunities from university (university network of industry contacts)				
	Shared infrastructure				

Figure 8: University to USO resource endowments in the Brazilian entrepreneurial university

The Brazilian model described in the preceding discussion differs considerably from the traditional model of the entrepreneurial university in several key ways. First, there are many more actors and stakeholders involved, including alumni networks of successful entrepreneurs, industry collaborators, and students. Secondly, there is a broader array of mechanisms utilised by the entrepreneurial university, including accelerator programmes, entrepreneurship competitions, and academic-commercial hybrid organisations (such as the ‘firm within a lab’). Traditional components of an entrepreneurial university – a TTO and incubator – are observed here to support entrepreneurs and USOs through a wide range of initiatives that are also far reaching: planting the seed of entrepreneurship in students early on, extending their remit of new firm creation to one of firm nurturing, and supporting resident firms in every facet of business management. They also exhibit a great deal of strategic competence, with clear aims, purposeful decision-making and ambitious future plans. The delivery of these mechanisms in Brazil – the former of which was likely renamed ‘Innovation Agency’ to reflect its enhanced scope of work – demonstrates that their potential exceeds far beyond what is traditionally considered to be their role in academic entrepreneurship.

A comment from Mauricio Guedes, Director of UFRJ science park, underlined the need for this broader remit:

“In Brazil, we have very strong experience regarding business incubators. [...] We have hundreds of business incubators all over the country. We have been quite successful in the creation of start-ups, thousands of new companies, but we have not been so successful in [helping] them grow” (Mauricio Guedes, Parque Tecnológico).

It is no longer sufficient to support the creation of new ventures. Rather, universities such as UFRJ are motivated to ensure the survival, and support the growth, of these firms.

Table 5 summarises the entrepreneurial actors, drivers, mechanisms and outputs of the emerging model of the entrepreneurial university evidenced in this study. The features of the traditional model have not been replaced by those in the emerging model: these were all evident in the case study universities. Rather, these traditional elements are a foundation upon which a model of diverse and creative initiatives has recently been built.

Table 5: Traditional and Emerging Models of the Entrepreneurial University

	Traditional Model	Emerging Model
Entrepreneurs	Academic faculty; post-doctoral researchers	Students; industry collaborators
Drivers	Commercialisation of research outputs as an additional revenue source Venture creation	Socioeconomic development and social innovation Venture growth and survival
Mechanisms	Technology transfer office; business incubator; science park	Innovation agencies (broader remit than TTO); entrepreneurship education; accelerator programmes; alumni networks; entrepreneurship competitions
Outputs	Patents; licensing agreements; spin-off companies	Collaborative partnerships; entrepreneur networks; academic-commercial hybrid organisations (e.g. 'firm in a lab'); entrepreneurial awareness and 'the entrepreneurial student'

An important evolution of the entrepreneurial university model is the greater significance of entrepreneurship education, which is increasingly becoming a part of higher education in Brazil; not just in engineering and the sciences but in humanities and the arts as well. This serves several purposes. First, it creates an 'entrepreneurial awareness' in the student population: opening minds to the possibilities and realities of business ownership. Secondly, it creates, in Etzkowitz's (2013a) terms, the 'entrepreneurial student': one who may not form a company upon leaving university but will be otherwise driven to become an 'intrapreneur' and innovate within existing organisations; the student that leaves university motivated to generate jobs, rather than simply find a job (Ortega and Bagnato, 2015). Finally, it also creates the opportunity for students to develop viable business plans whilst still undergoing their education, as supported further by initiatives such as entrepreneurship competitions. In those cases where students go on to create incubated firms, this education will continue under the incubator's business skills development training.

Entrepreneurship education is particularly important in Brazil (and, by extension, many other developing countries) for three reasons. First, as a subject, business studies (or similar) is not

taught as an academic subject in Brazilian secondary schools, which provides students with an early understanding of the various facets of business ownership. Second, and certainly related to this, is the perception of entrepreneurship in Brazil. It is a cultural artefact of the country that business ownership is generally regarded as either an unviable or undesirable option by students. Finally, and discussed by several of the interviewees above, the spin-off process produces a lot of naïve and ill-qualified business owners. The entrepreneurship education received prior to graduation and, where applicable, following incubation is critical to achieving the mindset change in the entrepreneur required at the Re-orientation stage in particular, and the development and survival of the company thereafter.

This has policy implications for Brazil. Whilst the university has taken a proactive role in addressing the need for entrepreneurship education, this nevertheless underlines the need for such an education to begin before students enter the university system. Further, the Brazilian model offers an array of possible support mechanisms that should also be available to entrepreneurs outside of the university system. Governmental support is currently focussed on financial assistance through grant and loan programmes for new ventures. However, this should be extended to include consulting services (which, it should be noted, are currently available through SEBRAE) and the provision of valuable market and technology information. The introduction of such services would benefit the country considerably with regards to business ownership rates, new venture survival rates and the broader domestic business environment.

A final point of note in the emerging model is the extent to which universities strive to create a collaborative environment on the campus. COPPE-UFRJ is certainly the clearest example of this in Brazil to date. The university pursues collaboration both amongst firms and also between firms and the university, the importance of which cannot be understated: “the most important thing that happens in [...] any park [is] the interactions between the actors” (Mauricio Guedes, Parque Tecnológico). The university recognises that this can be achieved through a single vision: a collaborative and innovative ecosystem on the campus. The involvement of the university is ensured through certain mechanisms: USOs maintain royalty agreements during their residency; and SMEs in the science park have a contractual commitment to invest a set expenditure in the university. Together, the science park and incubator satisfy a dual focus for academic entrepreneurship: the MNEs in the park engage with COPPE’s laboratories (as supported by the 1% Regulation), whilst the business incubator (and later, the science park’s multi-tenant buildings) provides a home for the university’s faculty and students who wish to commercialise university research outputs or otherwise collaborate with the university through

the creation of new ventures. These ‘umbilical’ relationships address some of the concerns that university-USO relationships decline quickly over time (refer Perez and Sánchez, 2003).

Ultimately, every aspect of the above – whether directly or indirectly – addresses the university’s desire to maximise the potential of its research outputs. A more populous and collaborative business incubator and science park provides more opportunities for technology transfer and laboratory engagement. This leads to higher levels of investment in the university, further income from the licensing of technology, and, perhaps most importantly, greater human capital gains with regards to the expertise within the university.

The success of the COPPE-UFRJ model is certainly due, in part, to the interrelationship between the firms, and between the firms and the school’s laboratories. The vast majority of activity in the science park is related to the petroleum industry, and this, too, is a considerable part of the school’s remit at present. The top-down initiatives of the government have also provided considerably for the incubator and science park, and the firms therein: directly, through the various public funding opportunities; and indirectly, as MNEs establish technology centres and invest in R&D projects with university laboratories and other firms so as to satisfy the 1% Regulation. Thus, sector specialisation is seemingly beneficial to establishing a collaborative environment at an entrepreneurial university. Sector specialisation is evidenced elsewhere in the case studies. For example, Campinas has been referred to as Brazil’s Silicon Valley, with UNICAMP equally known for its expertise in information technology. A considerable share of UNICAMP’s incubated firms are in software applications, whilst the adjoining science park is home to the university’s Innovation Centre for Software (InovaSoft) and the technology centre of Chinese computing MNE, Lenovo. Information Technology, like petroleum, is one of the core industries that benefit from enhanced sectoral funding from the government.

The nurturing of such a collaborative environment brings the academic and industrial spheres of the Triple Helix closer together. This is important in Brazil, which is noted for having weak linkages between industry and academia (Ortega and Bagnato, 2015). The utilisation of research outputs in industry is more assured in the developed world. Ortega and Bagnato (2015) note that many universities in the United States have wide-ranging agreements with companies of all sizes, and European universities often host companies on campus with a view to technology transfer. This has not generally been the case in Brazil. However, the evidence presented here suggests this may now be starting to change through the proactive intervention of universities. The case study universities are generating consumers for their innovations by creating new ventures and technology transfer partnerships. This ensures that university-

generated innovations are created in accordance with the needs of, and often in collaboration with, industry actors.

The bringing together of the academic and industry spheres was underlined by one comment from Mauricio Guedes at the UFRJ science park. The comment reflects not only that this is a primary mission of the park, but also the motivating principle behind it:

“Our mission is to transform knowledge into wealth. [...] COPPE [...] is the biggest research institute in engineering in Latin America. [...] We generate a lot of knowledge. [...] So, the mission of the park is to bring companies that can cooperate with the university, cooperate among the other companies, and to create [...] ways to transform [...] the knowledge created in our academic research in order to create jobs, to create new products, new services for the society. That is the mission of the park” (Mauricio Guedes, Parque Tecnológico”).

The creation of jobs and innovation for Brazilian society (i.e. social innovation) has been seen before in the country’s universities’ Popular Cooperatives initiative. When first transported from the United States, the incubator model was adapted to focus on low-technology solutions under this socially-minded mission. As the country’s leading universities have developed high-technology capabilities, they have also adapted the incubator model to reflect this, but have retained the mission of socioeconomic development.

The impetus of societal benefit can be observed in the fact that, as with its Popular Cooperatives initiative before it, COPPE-UFRJ is sharing its experiences in developing its entrepreneurial university model with other universities. And just as the Popular Cooperatives model has been replicated across the country over the last two decades, in the coming years we may see a growing number of Brazilian universities increasing their academic entrepreneurship efforts through new and diversified initiatives.

Finally, the Brazilian government’s top-down initiatives have serious shortcomings with regards to entrepreneurship. These are described at length in Chapter 2 of this thesis. These top-down interventions fail to address the need (and opportunity) for domestic firms to participate in the Brazilian petroleum industry, instead diverting tremendous funds to universities. The bottom-up initiatives of the case study universities address, to a considerable extent, many of these shortcomings. While the government’s interventions have indeed led to great investment in the country’s universities, domestic firms are also benefitting from this, albeit indirectly. The increase in expertise, sophistication of laboratories and equipment, and quality of research outputs – along with the increase in public investment for university incubator and science park projects – all benefit the resident firms. Universities are utilising

their resources to support domestic SMEs, thereby bringing a degree of balance to a policy and funding landscape that favours innovation in universities and MNEs. The case studies also illustrate the potential of universities to operate as an effective coordinating agent between disparate Triple Helix actors.

Conclusions

The notion of the ‘entrepreneurial university’ (Clark, 2001; Etzkowitz et al., 2000) emerged as universities began to formalise their technology transfer efforts, thereby challenging the label of universities as simply ‘knowledge suppliers’. However, the literature has failed to keep pace with the changing mechanisms, roles and drivers underlying this third mission of universities. This study has demonstrated that universities are evolving their academic entrepreneurship efforts into a much broader and more creative set of initiatives. These incorporate a greater number of actors and stakeholders, under a remit of socioeconomic betterment in addition to considerations of revenue generation. The case study evidence challenges the doubts of Geiger and Sá (2008) as to whether such initiatives will become an explicit mission of universities. The three case study universities exhibit strategic planning, clear aims and purposeful decision-making with regards to carrying out their third mission.

The findings align with the recent, broader discussion of the changing nature of universities from Crow and Dabers (2015). As those authors found in the United States, new and differentiated models of universities have emerged in order to address the broader needs of local communities and the nation. This presents opportunities for new directions of theoretical and empirical research in the realm of academic entrepreneurship and the entrepreneurial university. Whilst future research should reflect the greatly enhanced role of TTOs (or Innovation Agencies) and incubators, the role of entrepreneurship education in the entrepreneurial university model is particularly in need of attention. This teaching and education component has been neglected in place of a narrow focus on university-industry linkages and the commercial value of research outputs (particularly patenting, technology licensing, and the creation of new ventures from formal IP; Siegel and Wright, 2015b). This is an area for future investigation for researchers in academic entrepreneurship. A set of well-researched papers focussing particularly on this would offer a fuller account of the modern-day entrepreneurial university.

The research framework was created by combining the resource-based, stage gate approach of Vohora et al. (2004) with a taxonomy of possible resource endowments developed for this paper, thus offering an analytical model with which components of the emerging entrepreneurial university can be classified (refer Figure 7 above). The creation of such a model

is timely, given what is perceived to be a forthcoming evolution in academic entrepreneurship (recently observed elsewhere by Etzkowitz, 2013b; 2015; Siegel and Wright, 2015b). As Siegel and Wright (2015a) comment, “we have reached a juncture that requires us to rethink academic entrepreneurship, given the changing role and purpose of universities”. The framework can provide a useful basis from which researchers can empirically analyse further case studies of emerging models of the entrepreneurial university. Given that the Brazilian model (refer Table 5 above) has been drawn from three case study universities, there are undoubtedly further mechanisms in the country that have not been identified here, and countless other new initiatives being deployed by global universities. Empirical investigation of further cases using this framework would offer a more complete picture of modern-day academic entrepreneurship. It would also provide universities and policymakers with further ideas with which to construct their own version of the entrepreneurial university. The framework can otherwise form the basis for comparison or assessment of different versions of entrepreneurial university.

The study highlights the need for additional and/or adapted metrics by which to measure success in an entrepreneurial university. Externally, this assessment has typically been made through metrics such as patent and licensing activity and the creation of spin-off companies (e.g. AUTM, 2015 in the United States). However, the research presented here – particularly the transition academic entrepreneurship has made from a position of firm creation to firm nurturing – suggests that this should be considerably extended. Equally, universities must develop their own internal measures of success, so as to assess which strategies and mechanisms are successful, and to what degree. For example, the USP incubator, Cietec, reports on: the number of incubated companies and their combined turnover; the number of collaborative projects with industry actors; the total funding from public grants; the total investment made in incubated firms; how many skilled jobs have been created; the survival rate of incubated firms (during and beyond incubation); and the number of patents raised by incubated firms. A mind-set change in the academic community and broader society is required with regards to how university prestige is represented in reflection of this (as Crow and Dabers, 2015 have recently discussed under the context of the New American University).

Finally, this study has contributed to the limited body of research on developing country models of academic entrepreneurship (refer Etzkowitz and de Mello, 2004; Guerrero et al., 2014; Ortega and Bagnato, 2015). La Paz et al. (2010) state that the entrepreneurial university may be difficult to replicate in developing countries, due to cultural barriers, limited resources and risk aversion. Such hindrances cannot be observed in the Brazilian case studies presented here. This may be due to the fact that the Brazilian model of academic entrepreneurship has been driven as a bottom-up initiative, rather than something that has been thrust upon universities by

government. The government's role has been one of support, rather than control, from which the universities have enjoyed a significant degree of autonomy from government. The extent to which the model has been embraced and has subsequently prospered may also be a result of universities having the freedom to make the model their own. This is not strictly a case of replication of Western models but rather one of adaptation. The Brazilian model, as it now exists, has emerged from an ongoing period of modification to address the needs of the university's local community and those of the country's broader population. As such, it is designed to address the constraints to innovation, such as cultural barriers and constrained resources, that are present in the country. Other developing country governments can learn much from the Brazilian case and should strive to find a balance between the facilitation of academic entrepreneurship and granting universities the freedom to develop their own models thereof to best suit their environment.

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Chapter 4: The R&D internationalisation strategies of clustered multinational firms on Brazil's 'Oil Island'

Abstract

The geography of innovation literature includes comprehensive bodies of work concerning corporate R&D internationalisation and industry clusters. However, the interface between these two subjects – specifically the relationship between the R&D strategies of clustered foreign MNE subsidiaries and their host environment – has not yet been substantially addressed. This paper examines the notion that changes in the cluster environment will have a varying impact on subsidiaries depending on the R&D strategies they employ. This is explored through a study of the innovative activities of the technology centres of several of the world's leading petroleum companies. These technology centres have recently been inaugurated on Ilha do Fundão: an island just off the coast of Rio de Janeiro that for over fifty years has been home to Petrobras – Brazil's foremost oil and gas company – and the engineering school of one of the country's leading universities. The research is informed by in-depth interviews conducted in mid-2015 with the R&D managers of five technology centres. The study finds that four of the five technology centres were created with a technology-seeking R&D mission. However, two of these subsidiaries have recently changed R&D strategy in response to the current turmoil in Brazilian petroleum, so as to focus on global markets through vertical integration. The paper concludes that asset-augmenting strategies such as these, whilst prevalent in clusters, leave firms susceptible to changes in the cluster environment and/or macroeconomic and sectoral instability.

Introduction

Over the last three decades, corporate research and development (R&D) activities have been increasingly internationalised, as evidenced by the growth of foreign firms' share of total R&D expenditure in almost all countries for which data is available (Dachs and Zahradnik, 2014). This has occurred as part of a broader trend towards corporate internationalisation, including an increase in international trade and foreign direct investment (FDI), and the offshoring of manufacturing services (OECD, 2008; UNESCO, 2010; cited in De Prato et al., 2011). The study of the former phenomenon has formed a rich literature base around the R&D strategies employed by multinational enterprises in their host locations (e.g. Criscuolo et al., 2005; Kuemmerle, 1999; Le Bas and Sierra, 2002; Patel and Vega, 1999). Researchers have observed that companies decentralise their R&D activities to locations with a desirable knowledge base

and pursue opportunities for knowledge spillovers (Blomström and Kokko, 1998). Such a strategy is known as ‘asset-augmenting’ (Criscuolo et al., 2005), whereby a firm uses R&D investment “to improve existing assets or to acquire (and internalise) or create completely new technological assets through foreign-located R&D” (Narula and Zanfei, 2005).

However, a shortcoming of many studies of R&D internationalisation is that strategies are assessed within the national borders of a host location, or a firm’s internationalised R&D strategy is generalised across all foreign locations. For example, several leading patent-based studies examine the address of the inventor (i.e. whether this is the country of the company’s headquarters, or otherwise), and are therefore studies at the national level of analysis (e.g. Le Bas and Patel, 2005; Le Bas and Sierra, 2002; Patel and Vega, 1999). There is a need for a detailed examination of the R&D strategies of foreign firms within a single sub-national location – in this case, a cluster – so as to capture the idiosyncrasies of specific locations and how the environment thereof impacts upon the innovative activities of the hosted firms. This paper contends that these locational considerations matter a great deal to the R&D internationalisation strategies adopted by foreign subsidiaries. Whilst the literature has shown the effect the environment can have on a firm’s innovation performance (Furman et al., 2002), the focus here is on how the environment impacts upon the strategy that underpins a firm’s innovation activities.

The importance of geographical proximity is similarly highlighted in another facet of the geography of innovation literature: industry clusters. Clusters are defined as regional agglomerations of sectors or value chain related firms and other organisations (such as universities) that gain financial benefit from co-location and cooperation (Fromhold-Eisebith and Eisebith, 2005). Given the nature of tacit knowledge (which, as opposed to codified knowledge, is not easily articulated or transferred over significant geographical distances; Polanyi, 1967), innovation is most productive when conducted as a social enterprise, extending beyond the boundaries of the company to include other firms (customers, suppliers and competitors), research organisations (universities and public and private research institutes) and other intermediaries (e.g. industry groups). Regional agglomerations, such as industry clusters (as well as regional systems of innovation) therefore offer the optimum environment for innovation, under which a firm can benefit from localised learning processes and tacit knowledge exchange through interaction with other organisations (Asheim and Coenen, 2005; Asheim and Isaksen, 2002; Gertler, 2004). This paper discusses the foreign R&D investment within a single industry cluster: Ilha do Fundão in Rio de Janeiro.

Ilha do Fundão is an island to the North East of Rio de Janeiro city, connected by bridge to the mainland. The island is home to the city’s Federal University (UFRJ) graduate engineering

school (COPPE) and the national oil champion Petrobras' primary R&D facility, CENPES. The university created its science park a few years prior to the discovery of huge offshore oil reserves (termed 'pre-salt' oil) in Brazilian seas in 2007. This discovery, together with considerable intervention from the national government, created the conditions for sizable foreign R&D investment. This has seen eight leading global petroleum suppliers establish large technology centres in the UFRJ science park. The science park, which was originally conceived as a multi-sectoral space, is now a cluster for the petroleum industry. The cluster is extremely concentrated, given the number of firms present, the size of the technology centres and the small distances between them (all are within walking distance from one another). Competitors co-exist within a relatively small space, which itself is isolated from the central districts of the city.

Considering the significance of clusters to the process of innovation, and given the remit of many foreign firms to capture local benefits in foreign locations, this paper will explore how the cluster environment affects the R&D strategies of the hosted subsidiaries. The analysis does not extend to the R&D strategies of the sample firms in foreign territories (as is the focus of the majority of R&D internationalisation studies), nor those in Brazil. The focus is specifically on the activities of the technology centres located within the Ilha do Fundão cluster. The paper does not draw upon patent data, which is prevalent in the study of R&D internationalisation strategies (e.g. Almeida, 1996; Cantwell and Noonan, 2002; Le Bas and Patel, 2005; Le Bas and Sierra, 2002; Patel and Vega, 1999). Instead, the findings are derived from in-depth semi-structured interviews with the technology managers of the firms' technology centres. This allows for R&D internationalisation strategies to be discerned for these individual subsidiaries, along with an understanding of how these are influenced by the cluster environment.

Two important research questions are explored: how the cluster environment impacts upon the R&D internationalisation strategies of hosted foreign subsidiaries, and further, how changes in this environment lead subsidiaries to alter their R&D strategies.

The subsequent section discusses the literature relevant to the study. The methodology that was utilised is then presented. This is followed by an overview of the pre-salt development and recent investment on Ilha do Fundão. Subsequent to this, a detailed discussion of the empirical case is given. Finally, conclusions and theoretical implications are offered.

Literature Review

This section presents a literature review of the two bodies of research that are important to this study. Following this, gaps in this literature base will be identified and discussed, the research framework for data analysis will be presented, and research questions and hypotheses will be offered.

R&D internationalisation by multinational enterprises

There is an extensive literature around the internationalisation of R&D activities by multinational enterprises (MNEs). The phenomenon has many dimensions (Granstrand and Sjölander, 1992) and has been examined by researchers from a number of perspectives. Lewin et al. (2009) summarise the three types of arguments that have been advanced in the literature to explain the decision of firms to internationalise their operations. The market approach suggests that internationalisation is driven by the benefits that can be enjoyed from exploiting a firm-specific advantage in a larger market (Hymer, 1976). The internalisation approach applies transaction cost theory (refer Williamson, 1975; 1985) and states that MNEs will develop and exploit firm-specific advantages in knowledge within multiple locations as an alternative to utilising the external market for developing and exploiting knowledge (Buckley and Casson, 1976). Finally, the OLI-Model (Ownership-Location-Internalisation; Dunning, 1980) encompasses organisation-specific, locational and internationalisation advantages in describing FDI decisions. This paper is particularly concerned with this latter perspective. The research framework employed here (to be discussed momentarily) goes beyond the former two theories' 'access to markets' argument to also consider the technological advantages of corporate internationalisation. Both of these perspectives are captured by the OLI model.

Many of the theories that still dominate the discussion to this day were developed in the 1990s, and Zanfei (2000) summarises the three themes in the literature from Dunning's (1980) OLI perspective: a long tradition of internationalised R&D and patenting in MNEs since the 1960s (Cantwell, 1995; Dunning, 1994; Florida, 1997; Granstrand et al., 1993); foreign subsidiaries' pursuit of technology from diversified sources (Cantwell, 1993; Pearce, 1992); and subsidiaries' strong involvement in collaborative agreements (including those with local firms and institutions; Forsgren and Johanson, 1992; Ghoshal and Bartlett, 1990).

Several of these studies demonstrate that the internationalisation of R&D activities by MNEs is not new. For example, Cantwell (1995) found that in some major U.S. and European industries, the level of internationalisation of R&D activities was higher in the 1930s than in the 1970s and 1980s. However, the nature of this internationalisation has changed. Many studies share the view that the strategies and structure of MNEs has been altered due to changes

in the competitive environment (the increasing rate and widening scope of technological change, and the globalisation of markets; Zanfei, 2000). For example, in their study of twenty-one MNEs from Europe, Japan and the U.S., Gerybadze and Reger (1999) identified a substantial shift in the R&D strategies and international location decisions of MNEs since the mid-1980s. The authors report a 'new paradigm', whereby innovation is focussed on market and technology interactions, multiple centres of knowledge (in several locations), and cross-functional, cross-locational and bidirectional (i.e. inward and outward) learning and technology transfer.

This was similarly addressed by Zanfei (2000), who presented a new organisational mode – the 'double network' – that encompasses both an interconnection between a large number of internal functions in using and generating knowledge (the internal network) and the development of cooperative arrangements with other firms and institutions (external networks) in pursuit of knowledge generation. The latter does not only involve the central units of the firm but also the decentralised units as well, so as to benefit from local expertise and technologies (ibid). From this perspective, "the foundations of competitive advantage no longer reside in any one country, but in many" (Castellani and Zanfei, 2006). "New ideas and products may come up in many different countries and later be exploited on a global scale" (Hedlund, 1986). The challenge faced by firms in harnessing the double network comes in satisfying the need for foreign subsidiaries to be autonomous in order to achieve best results and utilise local benefits, and avoiding the 'centrifugal' forces that can constrain the flow of knowledge within the firm (Zanfei, 2000).

This type of internationalisation is often referred to as 'asset-augmenting' R&D (Criscuolo et al., 2005) but is also termed elsewhere as 'home-base augmenting' (HBA) R&D (Kuemmerle, 1999) and 'strategic asset-seeking' R&D (Dunning and Narula, 1995). As these labels suggest, such activity is driven by a desire to supplement the firm's existing knowledge and product offering through foreign-located R&D facilities. The location-derived advantages are often associated with the presence of other firms and institutions in the foreign location, such as universities and research institutes, which offer opportunities for technological spillovers, acquisitions and collaborations with these actors (Criscuolo et al., 2005). Innovation has come to be increasingly centred on interactions and knowledge flows between actors (Asheim and Gertler, 2005). Companies typically have their own R&D departments but also rely on the research outputs of universities and other research organisations in innovating (Asheim and Coenen, 2005).

However, the capturing of such opportunities is far from assured. Von Hippel (1994) described the 'sticky' nature of location-specific knowledge, which also brings the notion of tacit

knowledge (refer Polanyi, 1967) to the fore. The nature of tacit knowledge leads to innovation being unevenly distributed across a country. Innovation is localised, with spillovers between actors more pronounced in certain regions, particularly in the presence of universities and research institutes (Feldman and Florida, 1994; Jaffe et al., 1992), leading to the clustering of innovation activities (Audretsch and Feldman, 1996). It is therefore logical that a firm must be present in a region in order to be granted access to that region's specialised knowledge and expertise. Geographical proximity is an important dimension in achieving knowledge transfer under such a scenario (Blanc and Sierra, 1999) and will be returned to later in this literature review under the context of industry clusters.

An alternative strategy to asset-augmenting R&D is 'asset-exploiting' R&D, whereby firms look to utilise their existing technology base in a foreign location. This has been otherwise referred to as 'home-base exploiting' (HBE) R&D (Kuemmerle, 1999). A specific location may require products and/or processes to be adapted in order to meet the requirements of this new market. Thus, a relationship has been found between foreign production and foreign-located R&D (Criscuolo et al., 2005). Several researchers have shown that a transition from foreign production to foreign-located R&D can occur (Bartlett and Ghoshal, 1990; Håkanson, 1990), as local demand becomes increasingly sophisticated and companies utilise local R&D capabilities to satisfy the needs of the market (Lewin et al., 2009). Asset-exploiting R&D is, generally speaking, the traditional view of internationalised R&D. Vernon (1966), Kindleberger (1969) and Stopford and Wells (1972) conceived of a quasi-colonial relationship between the parent firm and its foreign subsidiaries: strategic decisions remain uniformly centralised at the parent firm; and the subsidiaries' role is almost exclusively one of technology adoption and diffusion (Narula and Zanfei, 2005).

Of the two strategies, the literature has shown that asset-augmenting R&D is growing in significance as a result of several factors, including: (i) the increasing expense and complexity of R&D, which has led to a growing need to pursue innovation opportunities with diverse and geographically-dispersed actors in possession of a complementary knowledge base; (ii) the faster rate of technological development in many industries, which has driven firms to seek location-specific application opportunities; and (iii) an increasing degree of government intervention in host countries, which demands interaction between MNEs and local actors as a prerequisite for access to foreign markets (Narula and Zanfei, 2005). The Brazilian petroleum industry is an example of a high degree of government-mandated interaction between actors. This will be discussed further later in the paper.

Several studies that followed Kuemmerle (1999) and Criscuolo et al. (2005) progressed this dichotomous model further. Le Bas and Sierra (2002) build upon the methodology of Patel and

Vega (1999) to offer four possible configurations of the internationalisation strategies of firms. This is based on a matrix of a firm's strengths and weaknesses with regards to R&D internationalisation and the home and host countries' technological profile. The four possible configurations are shown in Figure 9 and described thereafter.

		R&D activities in the host country	
		<i>Weak</i>	<i>Strong</i>
Corporate R&D activities in the home country	<i>Weak</i>	Strategy IV: Market-seeking FDI	Strategy I: technology-seeking FDI in R&D
	<i>Strong</i>	Strategy II: home-base exploiting FDI in R&D and technology	Strategy III: home-base augmenting FDI in R&D and technology

Figure 9: Four locational strategies for FDI in R&D (adapted from Le Bas and Patel, 2007; Le Bas and Sierra, 2002; Patel and Vega, 1999)

Strategy I: technology-seeking FDI in R&D (term from Shan and Song, 1997). This strategy is driven by a desire to address the home country weaknesses (with regards to technology and/or expertise) by selecting a host country with an established strength in those areas. The firm may choose to establish a foreign technology centre in order to advance its technological capabilities in these areas (Almeida, 1996; Chiesa, 1996), or to carry out technology acquisitions in the host country (Granstrand, 1999).

Strategy II: home-base exploiting FDI in R&D and technology. This type of activity is characterised by Kuemmerle (1999) as home-base exploiting R&D. It is the exact opposite of Strategy I. FDI is predicated on access to markets (von Zedtwitz and Gassmann, 2002; cited in Le Bas and Patel, 2007), the objective being to exploit the firm's existing capabilities in new territories. It is aligned with the notion of 'adaptation R&D' (Chiesa, 1996), whereby R&D activities are focussed on adapting the company's existing technology base to the host country market.

Strategy III: home-base augmenting FDI in R&D and technology. This asset-augmenting strategy is targeted at technologies that the firm has a relative advantage in and in which the host country is also relatively strong. Opportunities are sought in the host region, often in the form of cooperative arrangements with others actors, that can support the augmentation of the firm's existing knowledge base.

Strategy IV: Market-seeking FDI in R&D (term from Dunning, 1998). Under this scenario, the firm's investment is focussed on areas in which both the host and the home country are relatively weak. The foreign market, not the technology base, drives the strategy. Such a

strategy is often the result of mergers and technological acquisitions (Håkanson, 1992; Patel and Vega, 1999).

For the large part, the four strategies have been explored through quantitative studies (refer Le Bas and Sierra, 2002; 2005; Patel and Vega, 1999), which have found Strategies II and III to be dominant (i.e. numerically relatively more important than Strategies I and IV; Le Bas and Patel, 2007). These studies have analysed R&D-focussed FDI from a national perspective, as opposed to the regional analysis of this paper. Firms have been found to exhibit behaviours consistent with all four strategies simultaneously, even within the same regions (Cantwell and Piscitello, 2005; Criscuolo et al., 2005). However, there is a ‘dominant’ strategy in each case, which patent-based studies have exposed to most commonly be Strategy III (Le Bas and Patel, 2005), although in many studies this encompasses less than 50 per cent of a firm’s R&D activity (Le Bas and Patel, 2007). Strategy III and Strategy I have generally been increasing in significance over the last twenty years (Moncada-Paternò-Castello et al., 2011).

Within this four stage taxonomy, strategies are still either asset-exploiting (i.e. exploiting the assets of the parent firm), or asset-augmenting (i.e. acquiring or improving the firm’s technological assets). What distinguishes the two asset-augmenting strategies from one another, and the two asset-exploiting strategies from one another, is the strength of the parent firm’s knowledge base in the technological specialism that drives the investment. Thus, from the descriptions above, we can say that Strategy I and Strategy III are asset-augmenting strategies, whilst Strategy II and Strategy IV are asset-exploiting strategies. These strategies are summarised in Table 6. This shows the progression from a dichotomous classification to a bi-dimensional assessment of R&D strategy, along with the further cluster-specific adaptation that is utilised in this study.

Table 6: R&D internationalisation literature base and research framework

	First Generation	Second Generation	Research Framework
	<p>Dichotomous classification of R&D internationalisation (Criscuolo et al., 2005; Dunning and Narula, 1995; Kuemmerle, 1999).</p> <p>Data methodology: documentary analysis; survey data; patent analysis.</p>	<p>Four locational strategies for FDI in R&D (Le Bas and Sierra, 2002; Patel and Vega, 1999).</p> <p>Data methodology: large-scale patent analysis.</p>	<p>Strategies as per Second Generation, although focus is on a cluster location, rather than a host country, and involves the diachronic study of these strategies.</p> <p>Data methodology: in-depth case studies explored through interview data and documentary analysis.</p>
Asset-augmenting strategies	<p>Asset-augmenting R&D: activity is focussed on supplementing the firm's existing knowledge and technology bases through foreign-located R&D facilities, so as to pursue opportunities for technological spillovers, acquisitions and collaboration (Criscuolo et al., 2005).</p>	<p>S1 Technology-seeking FDI in R&D: a host country is selected for its established strength in technology and/or expertise that is a weakness in the firm's home country.</p>	<p>S1 Technology-seeking FDI in R&D: R&D activity is directed at capturing desirable local expertise and technology bases that offer new competitive advantages to the parent firm.</p>
		<p>S3 Home-base augmenting FDI in R&D and technology: targeted at a country with an established strength that is also a strength in the firm's home country.</p>	<p>S3 Home-base augmenting FDI in R&D and technology: R&D activities are directed at enhancing the existing competitive advantages of the parent firm.</p>
Asset-exploiting strategies	<p>Asset-exploiting R&D: activity is focussed on utilising the company's existing technology base in a foreign location, where the subsidiary's primary role is typically one of technology adoption and diffusion from the parent firm (Narula and Zanfei, 2005).</p>	<p>S2 Home-base exploiting FDI in R&D and technology: guided by a desire to utilise the firms' existing capabilities in new markets.</p>	<p>S2 Home-base exploiting FDI in R&D and technology: investment is focussed primarily on accessing new markets through adaptation of the parent firm's existing technology base.</p>
		<p>S4 Market-seeking FDI: a market-driven approach, although R&D activities are focussed on areas in which the host and home country are weak.</p>	<p>S4 Market-seeking FDI: investment is directed at technological areas in which neither the parent firm nor the cluster location hold a significant competitive advantage.</p>

The adaptation of the four stage taxonomy was made with confidence that, following some modification, the framework could support the examination of R&D activities within a specific location (in this case, a cluster). The changes made will be discussed comprehensively in the third part of this literature review. The four-strategies framework offers a valuable structure for analysis within this new conceptual context. The framework has already proven effective in studies at different levels of analysis: in sectors and countries (Le Bas and Sierra, 2002; Patel and Vega, 1999), and later at the firm level (Le Bas and Patel, 2005). This paper can be regarded as a further progression of this work to another level of analysis: that of clusters and regions.

A final point in this section of the literature review is to distinguish between the terms ‘research’ and ‘development’. More often than not, researchers will refer to the two in unison under the guise of R&D, as has been done throughout the preceding discussion. Despite an assumption in the literature that R&D is a homogenous activity (Cohen and Fields, 2000; Cohen and Levinthal, 1990), they are in fact distinct activities with different aims, knowledge bases and personnel and management styles (Barge-Gil and López, 2015). The purpose of research is the acquisition of new knowledge and it is more theoretical in nature, albeit still usually directed by a practical objective (Barge-Gil and López, 2014). Development is focused on the introduction of new or improved products or processes (OECD, 2005). Research requires specialised personnel who often work independently of the rest of the organisation, whereas development is more integrated with the other functional units of the organisation (Chiesa and Frattini, 2007; Leifer and Triscari, 1987; cited in Barge-Gil and López, 2014). The activities of research and development are often carried out by different departments or even in different locations (Chiesa, 2001). This is an important distinction to make, as when discussing the R&D strategies of the case study firms, this will be expressed in a manner that differentiates between the two terms.

Industry clusters and science parks

This brings us to a further significant body of literature: that of industry clusters. The concept of clusters was popularised by Michael Porter, who describes them as “geographic concentrations of interconnected companies, specialised suppliers, service providers, firms in related industries, and associated institutions (e.g. universities, research institutes, etc.) in a particular field that compete but also cooperate” (Porter, 2000). Porter (1998) advocated clusters as a source of competitive advantage for firms (as well as for regions), which offer access to specialised inputs, personnel, information, research institutions and industrial complementarities, resulting in increased productivity and innovation.

The foundations for much of the research in the field were laid by Marshall (1890), who termed what we now consider clusters ‘industrial districts’. The author formed a simple taxonomy of sources of external economies of scales in these industrial districts: technological and knowledge spillovers; the presence of specialised suppliers; and labour market interactions. The notion of these ‘Marshallian externalities’ asserts that localised innovation and economic growth emerges through specialisation in a particular industry, within what are termed ‘localisation economies’. The importance of localisation economies is challenged by another form of agglomeration economy: ‘urbanisation economies’, within which Jacob’s (1969) ‘diversification externalities’ contend that superior innovation performance is found in regions where knowledge spills over between different industries. The debate as to which type of agglomeration economy is more important endures to this day (van Oort, 2015). Nevertheless, Marshall’s notion of the social dimension of industry can be observed in the persistent emergence of clusters despite the rise of information and communication technologies (ICT). Whilst these technologies have simplified and advanced the extent to which information can be transferred between firms, regions and countries, this does not extend to knowledge and understanding (Morgan, 2004), which are tacit in nature. As such, geographical proximity is enduringly of great importance to the innovation process.

The cluster environment has been shown to strongly influence the innovation performance of the firms within the cluster (Furman et al., 2002), and more specifically, support these firms in foreign markets (Giuliani et al., 2005). Clustered firms also experience stronger growth and innovation performance than non-clustered firms (Audretsch and Feldman, 1996; Baptista and Swann, 1998; Swann et al., 1998).

Clustering supports knowledge exchange – an important input to the innovation process – through at least three mechanisms (Tan, 2006): firms located in diffuse locations are likely to have fewer interactions (formal and informal) with similar firms than those within close proximity (refer Saxenian, 1990; 1994); clustered firms have better access to informal information networks; and proximity to firms in related industries supports labour mobility, which is another source of knowledge transfer between organisations (Almeida and Kogut, 1999; Almeida and Phene, 2004). The R&D activities of individual firms, research institutes and universities spill over into the cluster environment, thereby benefitting those organisations in related industries. “From a purely technological point of view, R&D spillovers constitute an unambiguous positive externality” (Jaffe, 1986).

Locating in a cluster does not assure firms of these potential benefits, and economic activity alone within a cluster does not offer any advantage to clustered firms. This is affirmed by Silvestre and Dalcol (2009), who point to several empirical studies that highlight an abundance

of ineffectual clusters (Baptista and Swann, 1998; Beaudry and Breschi, 2003; Malmberg and Maskell, 2002; Martin and Sunley, 2003).

Researchers have discussed the role of competition and cooperation in fostering an environment conducive to innovation. Porter (1998) found that high innovation within a cluster is driven primarily by competition between the firms, although cooperation is also present (mostly vertical, involving companies in related industries and local institutions). Competition increases the productivity of clustered firms, drives the direction and pace of innovation, and stimulates the creation of new ventures (which itself strengthens the cluster; *ibid*). Conversely, Schmitz (2000) finds competition within clusters to be a leading reason for an absence of cooperation across the value chain. Cooperation has elsewhere been shown to be a source of competitive advantage for clustered firms (Piore and Sabel, 1984; Schmitz and Nadvi, 1999). Many studies observe a multitude of vertical cooperative linkages in clusters through the value chain (Lee and Park, 2006; Malmberg and Power, 2003; Schmitz, 2000; cited in Silvestre and Dalcol, 2009). However, these same studies emphasise the irrelevance or scarcity of horizontal cooperation between firms that are not related within the value chain

There is also an international dynamic to activities within a cluster. There is evidence that a significant share of a cluster's knowledge, market opportunities, suppliers and technology providers, and sources of investment are not local (Gertler and Wolfe, 2005; Uhlmann, 2008; cited in Komninos, 2015). The attraction of foreign firms to clusters can be explained through the six arguments of Porter concerning how cluster dynamics contribute to innovation (summarised by Simmie, 2004): a cluster allows the rapid perception of new market needs; it localises knowledge and information, and a knowledge-based economy is most successful when knowledge resources are localised; it facilitates collaborative relationships with local institutions; it supports the rapid assimilation of new technological opportunities; and, finally, it provides richer insights into new management practices.

With regards to MNEs specifically, such firms typically participate in a cluster via a subsidiary (Mudambi and Swift, 2010), which allows the firm to access, exchange, assimilate and leverage localised knowledge (Foss and Pedersen, 2002). Mudambi and Swift (2010) emphasise the need for firms to consider the structure of markets in which they compete and the composition of the cluster before making the location decision: "larger, R&D-intensive firms co-locating in technological clusters with other larger competitors can engage in high-stakes games of knowledge exchange that can damage the firm's competitive position". This is of particular relevance here given the composition of the Ilha do Fundão cluster.

The cluster concept has attracted significant attention from policymakers, who have embraced Porter's model as an instrument for fostering national, regional and local competitiveness, innovation and growth (Asheim et al., 2008). However, the concept has been met with significant criticism, most comprehensively addressed by Martin and Sunley (2003). The authors argue that the geographical and industrial definitions of Porter's work lack clear boundaries, failing to establish a spatial boundary or concentration of actors within which a location can be considered a cluster. Significant efforts from theorists and researchers have been focussed on understanding processes of innovation and learning in clusters, which has been important in establishing the localised nature of learning and thus the inherently geographical nature of neo-Marshallian externalities. However, considerable ambiguity remains as to how the concept can be spatially or functionally defined (Phelps, 2004).

Simmie (2004) suggests the ambiguity around the concept helps to explain its popularity in policy circles, where "it can mean all things to all policymakers". This, despite there being insufficient evidence that the presence of clusters actually contributes to sustained economic growth in local and regional economies (Wolfe, 2003). Martin and Sunley (2003) state that even enthusiasts of cluster theory struggle to offer examples of where "deliberate cluster promotion programmes [...] have been unambiguously successful". However, Fromhold-Eisebith and Eisebith (2005) would later present evidence from two cluster initiatives in Austria and Germany where policy intervention, combined with bottom-up initiatives from firms, produced cluster advantages to their members, including new collaborations, and increased exchanges of information, competitiveness and innovativeness. The authors argue that both policy and bottom-up interventions are strong options for localised innovation support, albeit a model of best-practice cannot be generalised broadly across a large set of regions.

It is beyond the remit of this paper to address Martin and Sunley's (2003) concerns with the cluster concept's theorisation, claimed benefits, or use in policymaking. This study concerns only one group of actors of the many involved in a cluster's development. The analysis is also conducted at the firm-level as opposed to the sub-national or national levels at which most of these concerns were raised. There has also been no direct policy intervention with regards to this cluster and it was created without an explicit objective of attracting industrial specialisation (to be discussed later in this literature review). The elasticity of Porter's definition will equally not be addressed here. The definition from Fromhold-Eisebith and Eisebith (2005) – "a regional agglomeration of sector or value chain related firms and other organisations [...] which derive economic advantages from co-location and collaboration" – adequately captures the dynamic amongst the case study firms and their host environment.

However, these perceived shortcomings of the cluster literature are worthy of note. The synthesis of these is the disputed importance of clusters (to national, local and regional economies). The paper addresses this debate, albeit at a firm level rather national or sub-national level of analysis. Further, the significance of localised collaboration to firms – which is argued by some authors (e.g. Gertler and Wolfe, 2004; Martin and Sunley, 2003) to be exaggerated by cluster theorists – is also examined in detail here. Finally, although policy has not played a direct role in the emergence of Fundão, the paper does conclude with considerations related to cluster policy.

Whilst Ilha do Fundão can be considered a cluster, the specific corner of the island in which the case study firms reside (along with around a dozen SMEs within multi-tenant buildings), named UFRJ Parque Tecnológico, also falls within the parameters of a further body of literature: science parks. Science parks are typically located close to universities and interact continuously with them (Guy, 1996), with a remit to provide technical, logistical, administrative and financial support to young enterprises (Lai and Shyu, 2005) and a management function that is actively engaged in technology transfer (Storey and Tether, 1998). Given their proximity to, and relationship with, a university, science parks are associated with activities of university-industry knowledge exchange and technology transfer, and the firms therein are often academic spin-offs (Oakey, 2007). A comprehensive discussion of the support mechanisms offered to entrepreneurs and small firms by the UFRJ science park (and adjoining business incubator) is presented in Chapter 3 of this thesis.

The composition of firms in science parks is typically predominantly SMEs and, as such, so too is the focus of studies at the firm level in the literature. An exception is the study from Filatotchev et al. (2011) of spillover effects from MNEs to local firms in Beijing's vast Zhongguancun Science Park (ZGC) – dubbed China's Silicon Valley (People's Daily, 2007) – which is comprised of several dozen MNEs and over one thousand SMEs. ZGC is examined elsewhere by Tan (2006) and Ramirez and Dickenson (2010) as a cluster, given the location's specialism in semiconductor, computer and telecommunication firms. Science parks can often prove to be a precursor to the development of a cluster and there are many examples of clusters such as ZGC that started life as a science park. Most notable of these is Silicon Valley, which emerged from the founding of Stanford Research Park in the 1950s. In acknowledgement of this, science parks are increasingly being promoted as a mechanism for regional development and technology transfer, as they often lead to the clustering of fast-growing, industrially specialised firms (Filatotchev et al., 2011).

This illustrates that there is a considerable degree of similarity between the two concepts. Ylinenpää (2001) suggests that science parks are one category of cluster. However, the two

have distinctive characteristics from one another, namely: the proximity and involvement of a university is not a prerequisite of a cluster; nor is industrial specialisation a necessary condition of a science park. Clusters are also typically comprised of a broader configuration of firms, whereas science parks are the host of, almost exclusively, local SMEs, and are designed so as to encourage the creation and development of such firms. Each concept possesses a distinct body of literature, which rarely converges.

In approaching this study, a decision was taken to evaluate the case study firms as residents of a cluster, rather than a science park. This was made for several contextual and theoretical reasons. First, the high degree of specialisation in the location (which has led to it being referred to by some as *Ilha do Petróleo*: Oil Island), coupled with the high number of MNEs within the science park, are closer to typical traits of clusters than science parks. Further, whilst the science park has a significant management structure that extensively supports local SMEs (refer Chapter 3), this is not within the remit of this paper, and therefore the consideration of Fundão as a cluster is more befitting. Thirdly, some central tenets of the cluster literature – localised learning, knowledge exchange and collaboration – are important to the focus of this paper, and further support the adoption of clusters as the contextual setting for the forthcoming analysis.

Finally, it is important to also make the distinction between the concept of industry clusters and that of regional systems of innovation (RSI). Whereas the concept of national systems of innovation (refer Freeman, 1987; Lundvall, 1992; Nelson, 1993) assumes homogeneity within a country (Schrempf et al., 2013), RSI analyses innovation activity in regional economies. Cooke (2004) defines such systems as “interacting knowledge generation and exploitation subsystems linked to global, national and other regional systems”. As with the industry cluster literature, the nature of tacit knowledge and significance of geographical proximity has been comprehensively addressed in the RSI literature (Asheim and Isaksen, 2002).

Whilst the concepts of industry clusters and regional innovation both belong to the theory of territorial innovation (Moulaert and Sekia, 2003), they should not be conflated (Asheim and Coenen, 2005). The difference again lies in the homogeneity of the firms within the geographical area. Whereas a cluster contains firms in the same or complementary industries, an RSI will typically contain firms from several different industries. Underpinning this within the RSI literature is the conceptualisation of two sub-systems within an RSI: one in which universities and research and innovation (R&I) institutions engage in knowledge exploration, and one in which firms engage in knowledge exploitation (Cooke, 2007). Clusters therefore largely exist within a knowledge exploitation sub-system. Further, clusters and RSIs can (and often do) co-exist in the same territory (Asheim and Coenen, 2005).

The distinction between the two concepts is important to make. The science park of Ilha do Fundão was conceived as a multi-sector space. However, the pre-salt discoveries and ensuing sectoral policy interventions created agreeable conditions under which the available land was acquired at great pace and almost exclusively by petroleum firms. Although the university is now looking for greater diversification in the firms that are to occupy the remaining land on the island, an industry cluster has been established. The emergence of the island as a cluster will be discussed further in the relevant section of this paper.

Research Framework

The literature review has highlighted an extensive body of research in both corporate R&D internationalisation and industry clusters. However, the research into the interface between the two subjects is slight (Birkinshaw and Solvell, 2000; Cook et al., 2012). Studies have shown the attraction of foreign MNEs to clusters, (Head et al., 1999; Wheeler and Mody, 1992), that a significant level of foreign investment is in clusters (Kozul-Wright and Rowthorn, 1998), and that this investment is increasing (Nachum and Keeble, 2003). Similarly, the link between corporate innovation performance and clusters is also well documented in the literature (e.g. Baptista and Swann, 1998; Beaudry, 2001; Beaudry and Breschi, 2003; Beaudry and Swann, 2009). However, to date, empirical studies have failed to address the R&D-focussed investment of clustered foreign subsidiaries, the strategies driving this investment, and the ways in which the cluster environment is a factor in the R&D strategies adopted by these subsidiaries. It is argued here that both the innovation performance and the underlying strategy behind innovation activities are influenced significantly by the cluster environment.

The cluster environment, as referred to in this study, is assessed primarily by the presence of cooperation between the actors (be it collaboration, knowledge exchange, or other social interaction), the individual level of R&D activity and productivity of each actor, and the linkages to local market actors and research institutes. The following research questions guide the study:

1. How does the cluster environment impact upon the R&D internationalisation strategies of hosted subsidiaries?
2. How do changes in the cluster environment lead foreign subsidiaries to alter their R&D strategies?

The aforementioned four strategies model has often been used as the basis for describing company-wide strategies for R&D internationalisation. The lack of focus on individual foreign subsidiaries is seemingly a shortcoming of the literature. Similarly, the prevalence of patent

analysis in the literature also fails to isolate specific subsidiaries (and therefore regions or clusters) for examination. Patent data also only offers insight into one aspect of innovative activity, as will be discussed further in the subsequent section of this paper. This too is considered a shortcoming of many of the empirical studies to date.

Consequently, the four-strategy framework has been extended and reworded for use in this paper, in several ways. First, it is helpful to establish revised definitions for each of the four strategies. Whilst the existing framework supports the examination of R&D strategies in a cluster setting, the definitions of the underlying strategies have been reworded (although still derived from the existing literature) so as to add clarification given the change in context. These are shown in Table 6 above.

The change in the level of analysis and data methodology has also led to some adaptation of the original framework. In preceding patent-based studies, the x-axis has addressed the strength of the host location in a certain specialism (as this is specifically what the researchers were measuring). However, the four strategies can otherwise be differentiated as asset-exploiting or asset-augmenting (as in Table 6). The use of interview data allows both the host location dynamic and the asset-exploiting/asset-augmenting dichotomy to be captured through specific questions. Therefore, the strategies have been characterised on the x-axis here as asset-exploiting and asset-augmenting to add clarity as to the underlying primary motive behind these strategies.

Similarly, the y-axis has also been reworded for clarification. The notion of a 'home country' is problematic in discussing multinational enterprises. In patent-based studies, such as Le Bas and Sierra (2002), researchers assign a firm's home country as that in which the firm is headquartered. For a particular technical field, strength is measured by the firm's share of patents invented in the home country in that field, relative to its total patent output in the home country. However, home country patenting is not a reliable indicator of an MNE's existing strength in a particular field. Firms will choose to patent in certain countries and not others for a multitude of reasons, and the headquarter location is often not the country in which the R&D activity is performed. Further, the original framework only addresses the relationship between the home location and a specific host location, thus ignoring the fact that multinational firms conduct R&D activities across borders and between subsidiaries, and disregarding the firm's R&D activities in other locations, which should also be considered part of the firm's native capabilities. This is a shortcoming of the use of patent data but a compromise that need not be made with the use of interview data.

Consequently, the research framework refers rather to the ‘MNE parent technological advantage’: that being the extent to which the technical field(s) in question are existing and developed competencies of the firm (including its headquarters and all other subsidiaries). Interview questions were directed at ascertaining the extent to which existing technological advantages were being utilised in the clustered subsidiary: ‘strong’ is indicated by R&D activities in the subsidiary being directed largely at enhancing the firm’s current technological portfolio; ‘weak’ is signalled by R&D activities that are designed to harness new technologies for the firm.

The use of interview data introduced a significant degree of subjectivity to the framework but this also allowed for the capturing of a more holistic and nuanced discussion of R&D strategy beyond the bi-dimensional analysis captured through patents. This includes denoting not only the current strategy of these subsidiaries but also how these strategies have changed, and why. This again extends the scope of analysis from which this framework emerged. Many studies of this subject are static, capturing a single moment in time, and do not consider this additional dimension. This paper offers a much-needed diachronic perspective on the phenomenon. Accordingly, the framework has been adapted so as to denote both the current and initial (i.e. that at the time of a subsidiary’s inauguration) strategies of the case study firms, with an arrow indicating any change between the current and initial strategies (refer Figure 10).

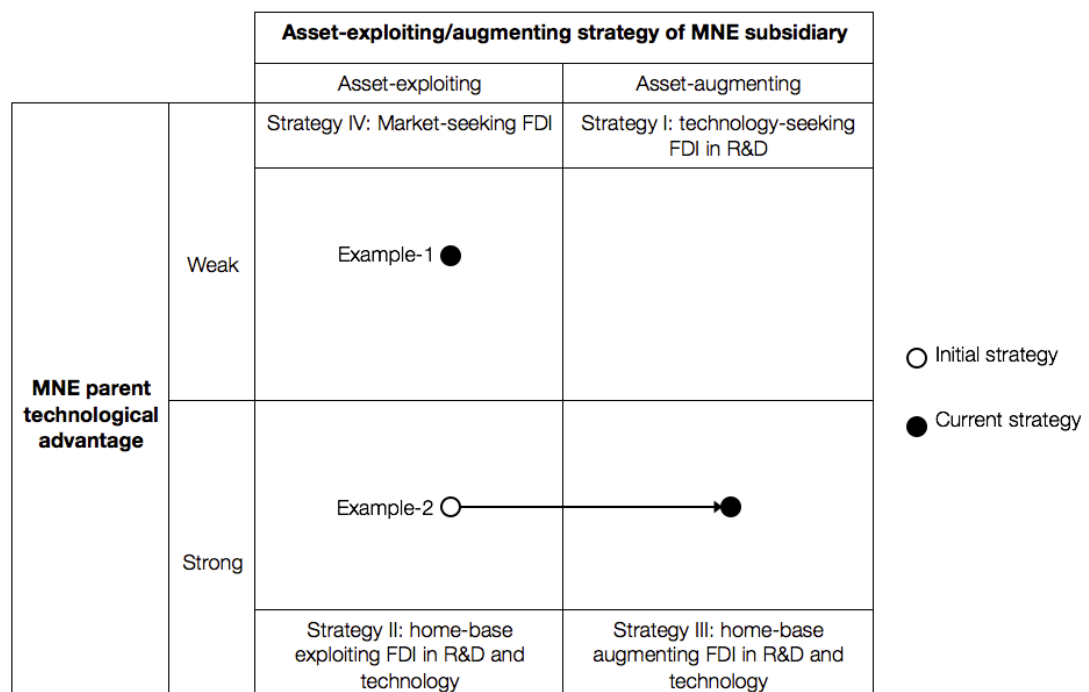


Figure 10: Example of R&D-focussed investment strategies of clustered foreign subsidiaries

A cluster in its infancy offers an ideal context in which to study the potential environment-driven change in R&D strategies. As Ketels and Memedovic (2008) note, a cluster's nature can change over time. Shocks can occur, particularly in the early stages of a cluster's life, that shift it from its potential trajectory. Further, the oil and gas industry is uncommonly global in nature (Hatakenaka et al., 2006), thus making it a useful context under which to examine R&D internationalisation. Petroleum MNEs have been noted for managing technology development through markedly different approaches from one part of the world to the next across their global operations (Perrons, 2014). This also supports the decision to conduct analysis of R&D activities at the individual subsidiary level.

Finally, it is also important to note that almost all of the research on the subject of R&D internationalisation has concerned those subsidiaries located in technologically advanced economies (Amighini et al., 2013), which, as one might expect, are generally developed nations. Although a developing economy, Brazil (and specifically Rio de Janeiro) can certainly be considered a knowledge-rich location with regards to oil and gas. However, one must also be mindful that the pre-salt presents a new technological paradigm in petroleum for many technical disciplines. This will be discussed further in a subsequent section of this paper. The case studies presented here can offer insight into the R&D activities of MNE subsidiaries under a scenario of great technological uncertainty.

To summarise, the preceding discussion has established that clusters are a source of localised learning, knowledge exchange and collaboration; multinational firms often pursue such opportunities in a cluster through a subsidiary, once a desirable knowledge base has been identified; and such a strategy is referred to as 'asset-augmenting' (Strategies I and III in the framework), whereby a firm aims to supplement its existing knowledge and technology bases through spillovers and collaborations. Consequently, it was anticipated that asset-augmenting strategies would be more common than asset-exploiting strategies (Strategies II and IV) in the clustered case study firms. Hence, in addition to the above research questions, the first of two hypotheses that are also explored in this study is:

- i. The majority of the case study subsidiaries will exhibit asset-augmenting R&D strategies (Strategies I and III, as differentiated by the strength of technological advantage of the parent firm);

Further, given that an asset-augmenting strategy is directed at accessing local knowledge and technology bases, we can deduce that a cohesive cluster environment is of greatest importance to those firms exhibiting asset-augmenting strategies. Thus, where changing cluster conditions lead to locational advantages (i.e. opportunities for learning, knowledge exchange and

collaboration) being unattainable, this will impact those subsidiaries exhibiting an asset-augmenting strategy to a greater extent than those adopting an asset-exploiting strategy. Therefore, the second hypothesis of the study is:

- ii. The productivity and level of R&D activity of those subsidiaries exhibiting asset-augmenting strategies will be adversely affected by a negative change in the cluster environment (i.e. fewer opportunities for collaboration and knowledge exchange amongst the cluster's actors).

Methodology

The primary data source for this paper is interview data, which was collected over two month-long visits to Brazil in April 2014 and May 2015. The data collection remit of these visits extended beyond that of this paper to also include the role of governmental policy (refer Chapter 2) and public universities (refer Chapter 3) in creating innovation and entrepreneurship opportunities through the country's petroleum sector. The interviews of greatest significance here were held with the technology managers of the five Ilha do Fundão-located MNEs that agreed to participate, as well as those with the UFRJ science park management and, to a lesser extent, the interviews with three technology managers at CENPES. The interview data has been supplemented by secondary data sources from the MNEs, UFRJ science park and the Brazilian news media, which have been used to offer a historical context around the creation of the cluster and technology centres therein.

Of the eight petroleum MNE technology centres that are currently in the cluster (all of which are first tier suppliers), seven had been inaugurated at the time of the fieldwork visit in May 2015. Two of these seven declined to be interviewed. All interviews were conducted at the Ilha do Fundão technology centres of the firms in a semi-structured manner. The semi-structured approach granted the subjects flexibility in their response and supported the gathering of detailed contextual information, whilst also providing a reasonable degree of structure to the discussions. Questions were focussed on the technology centre rather than the company's operations in Brazil or foreign territories in general. The interview structure is detailed below:

1. General information: number of employees, size of the lab and facilities, current and future investment, annual R&D budget;
2. Technology strategy: significance and direction of investment, how R&D efforts are organised/managed, relationship with the company's other technology centres and headquarters, nature of innovation (adaptive/innovative, research/development/

engineering, niche/core, complementarity), drivers and challenges of innovating, main successes to date, determinants of investment, sources of knowledge;

3. Cluster environment: benefits of location, share and importance of local expertise, interaction with UFRJ (and other universities), interaction with the science park and incubator, benefits of proximity (to CENPES, COPPE, and other firms), drivers of collaboration, importance of collaboration, how collaborative arrangements are organised/managed;
4. Industry: significance and effectiveness of government interventions, challenges for domestic firms in the industry, current and future state of Brazilian petroleum.

This interview protocol was developed following a review of the literature and subsequently revised following the first fieldwork visit to Brazil in early 2014. The duration of most interviews was between one and two hours, all of which were recorded. All interviewees spoke English, hence a translator was not required, and gave their permission to be recorded. Several interviewees have requested that both their identity and that of their employer be anonymised. This has been complied with in all such cases.

Despite the prevalence of patent analyses in the study of corporate R&D internationalisation, such an approach has not been adopted here for three reasons. First, although the researcher is competent in carrying out patent analysis, a process by which patents could be reliably isolated to just those generated by Ilha do Fundão technology centres could not be envisioned. Patent studies often examine the patenting activity of a group of firms in a foreign country. However, this paper is focussed on a cluster and the R&D activities of the technology centres therein: it is not appropriate to utilise patents raised in Brazil to draw conclusions about the R&D activity within one location. Secondly, even if these patents could be isolated for the specific technology centres, given that the centres are still in their infancy, it is questionable how much data would be available at this time. The time lag associated with patent data is described in Arora et al. (2013). Finally, as an indicator of R&D, patents often fail to capture the full extent of a firm's innovative activity. As Gök et al. (2015) explain, only a small share of R&D activity might result in patenting, and firms may choose not to patent for strategic reasons. A firm may otherwise choose to patent not to commercialise that technology but to prevent a competitor from doing so (Kleinknecht et al., 2002). This paper pursues a more holistic perspective of R&D activity.

Given the weaknesses of patent-based approaches and the desire for a holistic, spatially-bounded investigation, the decision was taken to adopt a case study approach. Yin (2003) describes such an approach as “an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon

and context are not clearly evident”. A case study approach supports both the theoretical and empirical objectives of this study. With regards to the empirics, it was important that research be conducted at the cluster, for a nuanced and detailed examination of the individual cases. The objective was to not only discern the R&D strategies of the clustered subsidiaries and how these might have changed since they were inaugurated, but also the drivers behind this change. As commented by Iacono et al. (2011), qualitative methods such as case study research are concerned with the meaning rather than frequency of phenomena. The latter has been the prevalent focus of R&D internationalisation studies to date.

Case studies also allow the researcher to “‘close in’ on real-life situations and test views directly in relation to the phenomena as they unfold in practice” (Flyvbjerg, 2006). This notion of testing views through case study research is referred to elsewhere as ‘theory testing’ (Eisenhardt, 1989), whereby “well-formulated theories are tested for their applicability and explanatory power” (Ridder et al., 2009). This describes the theoretical context of this study. There are well-established theories around the R&D internationalisation strategies of firms. Rather than ‘theory building’ (refer Eisenhardt, 1989), this paper adapts an established analytical framework from the literature and tests its suitability to qualitative data sources and specific spatial and temporal considerations.

Theory testing also involves the researcher establishing a set of hypotheses (termed a ‘preliminary theory’ by Yin, 2003) in advance of data collection, which is then utilised in all other stages of the research process (Løkke and Dissing, 2014). Under such research, theories serve as both an input and an output to the research (Campbell, 1975; Eckstein, 1975; Eisenhardt, 1989). In this study, the extant literature guided the formulation of the research strategy and accompanying hypotheses. However, it was clear from this same literature base that there was considerable scope for theory development (in the form of concepts, theoretical constructs, a conceptual framework, propositions or a mid-range theory; Eisenhardt, 1989; Eisenhardt and Graebner, 2007) given that the interface between the two bodies of literature – corporate R&D internationalisation strategies and industry clusters – is yet to be substantially addressed.

Ilha do Fundão and the pre-salt discoveries

Oil and gas have been a significant part of global energy demand for decades and appear destined to remain so for many years to come (Bullis, 2009; Fischer, 2007; Yergin, 2009). Given that the world’s ‘easy oil’ reserves have been almost exhausted, there is an increasing demand for advanced technologies for the exploration and production of offshore reserves in deeper, more remote, and more complex environments (Lord, 2007; Managi et al., 2004; 2005;

Paul, 2007). However, the industry has a reputation for being slow in developing and adopting innovations (Perrons, 2014). This has been attributed to the extreme risks and high costs of failure involved in offshore drilling, which lead many oil operators to be risk averse to technology acceptance (Daneshy, 2003; Rao and Rodriguez, 2005) and too often adopt a technology strategy of ‘fast follower’ rather than ‘first mover’ (Daneshy and Donnelly, 2004). Companies in the oil and gas market often use shared asset-ownership models in order to manage risk. However, this also often leads companies to adopt a secretive approach to innovation, so as to avoid new technologies being immediately absorbed and replicated by the other partners. The sector has been described as “slow clockspeed” (i.e. clockspeed being the rate of change in an industry; Fine, 1998), “low- and medium-tech” (von Tunzelmann and Acha, 2005), and “technologically timid” (Lashinsky, 2010; cited in Perrons, 2014).

Oil operators specifically have further been characterised as ‘low R&D intensity’ as a result of historically investing less than 1% of net revenue in R&D (Perrons, 2014; von Tunzelmann and Acha, 2005). This tendency of low R&D intensity can be traced back to the oil glut of the 1980s, which dramatically reduced the oil price and led to a significant reduction in the in-house R&D programmes of oil operators in that decade and the next. In response, equipment and service suppliers increased their R&D output (Rocha, 2012). However, one operator that was an exception at this time was Petrobras. The oil price crash coincided with both the aftermath of the 1983 debt crisis in Brazil and the discovery of vast offshore, deep water oil reserves. As many operators suspended development of deep water petroleum in other regions, Petrobras accelerated development of these newly-discovered fields and would venture into increasing depths in the subsequent decade (Dantas and Bell, 2011). Whereas mature oil provinces favour those operators that can build a strategy around low cost and environmental protection (Harris and Khare, 2002), in immature provinces, such as Brazil, large R&D investments can be observed, particularly with regards to technologies for deep and ultra-deep water exploration and production (Silvestre and Dalcol, 2009).

Today, many companies in the industry have embraced ‘open innovation’ (refer Chesbrough, 2003) and collaborative models of R&D, which seek out opportunities from other industries (such as Shell’s ‘Gamechanger’ programme, detailed in Ramírez et al., 2011 and Verloop, 2006). This is attributed by Perrons (2014) to the costs associated with modern R&D projects (in any industry), with technology now “so sophisticated, broad and expensive that even the largest companies cannot afford to do it all themselves” (Leonard-Barton, 1995). A defining characteristic of technological development in the industry today is how it is distributed across diverse actors and undertaken in collaborative arrangements. This typically involves operators, suppliers and universities (Acha and Cusmano, 2003; Dantas and Bell, 2011; Furtado, 1997)

and even direct competitors (Crump, 1997). A 2014 study of R&D activity in the oil industry from Perrons (2014) emphasises the relationship between operators and their suppliers in particular. Operators rely on their suppliers more than any other knowledge source and, conversely, service companies consider operators to be a particularly valuable knowledge source.

Unlike most national champions, Petrobras was not created as a mechanism to appropriate windfall gains from oil (Rocha, 2012). In 1953 – the year of the company’s inception – there was very little oil available in Brazil. From the outset, Petrobras has relied on an investment strategy focused on technology development and competence building in establishing one of the country’s leading industries from the ground up. One of the most important decisions the company made in those early years was to establish a technology centre (CENPES) on Ilha do Fundão in 1963, at that time home to several schools of UFRJ, including COPPE. For over fifty years, the island has been host to an important and fruitful collaboration between these two organisations, which has established a specialism in deep and ultra-deep water technologies and associated competencies. Details of a sample of key technologies that have emerged from this collaboration are outlined in Dantas and Bell (2011).

For much of this time, large areas of this mostly artificial island have laid empty. Today, that has changed. Ilha do Fundão is now also occupied by the technology centres of eight leading companies in the global oil and gas industry, emerging as a cluster of innovation in the sector. As one interviewee told me: “a new world has been created” (Interviewee-C, MNE-3).

Ilha do Fundão’s transformation has centred around the university-owned science park in the south of the island. Adjacent to this is the university’s business incubator, which has recently expanded from one multi-firm building to three. A thirty-minute walk from the science park leads to CENPES, and in between this lies COPPE. CENPES has also seen considerable growth in the last few years; doubling in size to 300,000 square metres at a cost of US\$ 700 million, thereby becoming one of the largest R&D centres in the Southern Hemisphere (Tautz, 2015).

Technological and innovation capabilities on the island are further enhanced with the arrival of the new residents on the island, including Schlumberger, Baker Hughes, Halliburton, FMC Technologies, Siemens, BG Group and Vallourec. These firms have invested heavily in the area, establishing large and expensive R&D centres. For example, FMC’s 20,000 square metre facility cost around US\$25million to build. For the company, “the location of the centre, inside the University campus, will create a collaborative environment and enable access to the very best of Brazil’s academia” (FMC Technologies, 2010). The construction of these technology

centres has occurred at great pace, as evidenced by the fact that the science park's assigned area of 350,000 square metres was vacant prior to 2010 but is now nearing maximum capacity.

When observed in person, what is most striking – along with the scale of the development – is the sheer concentration of firms in the cluster: eight of the world's leading oil companies all within walking distance from one another, including, in some instances, direct competitors immediately next to each other. Experts have identified this concentration as a unique advantage when compared with other petroleum clusters, such as Houston, offering a “unique opportunity in the world. [...] An intense exchange of innovation and experience, geared specifically to developing the best and most comprehensive technology for the pre-salt” (UFRJ Science Park Director, Mauricio Guedes; cited in Lima, 2011).

A map of Eastern Rio de Janeiro city is shown in Figure 11; Ilha do Fundão is highlighted. The image thereafter (Figure 12) shows the island as a whole, which illustrates the close proximity in particular of CENPES to COPPE, as well as those organisations' proximity to the business incubator and science park. It also highlights the new site for development on the island, which has recently become the home to General Electric's multidisciplinary technology centre. The third image (Figure 13) centres on the South-Eastern corner on the island, illustrating the proximity of the eight now-inaugurated technology centres (all of which are within six hundred metres of one another), and their proximity to the multi-tenant buildings of the science park and incubator.

Ultimately, the development of the science park has been driven by the discovery of the pre-salt reserves, which have proven an attractive investment proposition for industry leaders. Each firm's motives for investment are different, and these will be discussed within the context of each case in the subsequent section. Some emphasise the prospect of collaborating with Petrobras; others underline the broader opportunities for collaboration within the cluster (such as COPPE and domestic firms). One consistency, however, is recognition of the knowledge base that already exists on the island as a result of the long-standing relationship between CENPES and COPPE, and a desire to pursue similar collaborative opportunities with these and other actors in the cluster. And whilst the pre-salt poses considerable technical challenges in many of the disciplines in which these firms specialise – as is discussed subsequently – it nevertheless provides these firms with an important impetus for R&D investment and an opportunity to develop new competitive advantages for the Brazilian market and beyond.

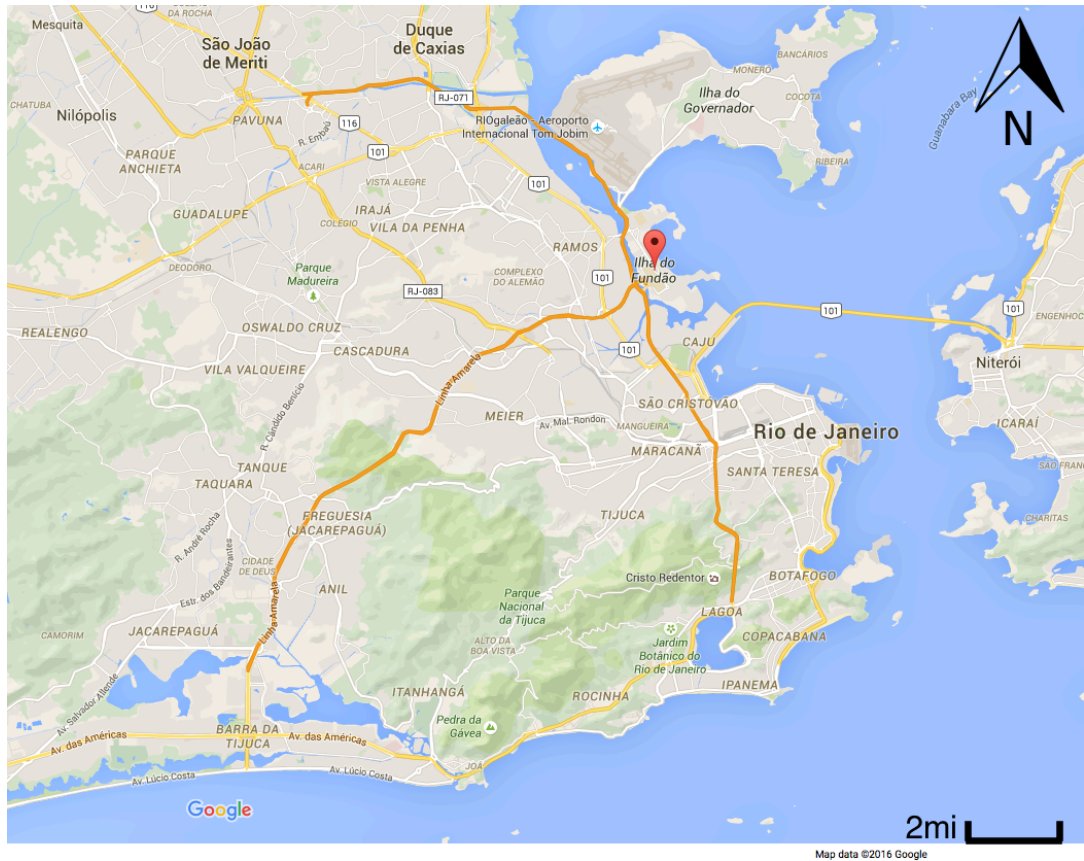


Figure 11: Map of Eastern Rio de Janeiro city (Ilha do Fundão highlighted)

The pre-salt reserves are unique to the world of petroleum: located at up to 7000 metres below the sea-surface, under a thick layer of salt. This unique environment for the exploration and production of oil and gas presents a new technological paradigm in many technical disciplines. The drilling equipment must withstand unprecedented extremes of pressure given the depths involved, and the salt layer itself, although in a solid state, has been found to swell and shift during the drilling process. Several of the global equipment suppliers on the island are developing specialised tooling to address this challenge. The oil is extracted at temperatures of over 80°C, which must then pass through components that are only just above freezing. The reserves are composed of a comparatively high gas to oil ratio and this mix includes corrosive gases. The global pipeline specialist Tenaris – one of the case study firms here – are exploring the development of new coatings and anti-corrosion technologies to tackle this, along with improved welding techniques to compensate for the extremes of pressure and offer assurances as to the reliability and lifespan of the pipelines.



Figure 12: Map of Ilha do Fundão, Rio de Janeiro



Figure 13: Map of UFRJ Science Park, Ilha do Fundão

The oil is heavy (i.e. high in density and viscosity), the extraction of which is much more complex and expensive than lighter reserves. Therefore, several suppliers are focussed on developing technologies that will offer significant cost and schedule reductions, so as to increase the productivity and economic viability of the wells. The distance of the pre-salt region from shore also presents challenges with regards to emergency management – a technical discipline in which there are significant opportunities for domestic firms – and pipelines.

The pre-salt also provides a unique and unprecedented challenge with regards to reservoir modelling (a computer model that supports decision-making by modelling well characteristics such as the porosity, permeability and water content of the seabed in a given area). Data acquisition (and its appraisal) is of the utmost importance in ultra-deep water. There is a need to reduce uncertainties and minimise risk given its costly nature (Pizarro and Branco, 2012). Besides the depths of the wells, the composition of the reservoirs (particularly the uneven surface of the salt layer and internal variations between the layers) also reduces clarity and the accuracy of seismic data from the model (Estrella, 2011). Without accurate models of these fields, the integrity of a drilling operation would be undetermined and costs could escalate to the point of making production unprofitable. Three of the case study firms presented here have a particular specialism with regards to reservoir modelling.

Whilst these technical challenges are considerable, they nevertheless offer an opportunity to the companies who can effectively address them. Harnessing these technologies would offer a competitive advantage beyond the Brazilian pre-salt. Similar reserves are thought to exist off the coast of West Africa, and these technologies would offer significant productivity increases and cost reductions within a highly-competitive marketplace. Thus, there is the potential for a highly specialised and localised knowledge base to emerge from the cluster in the coming years.

Brazil's national government has encouraged foreign R&D investment in this industry through the enactment of the '1% Regulation'. This regulation (Federal Law No. 9.478/1997, Article 8) assures all operators in Brazil's high-yielding oil fields pay 1 per cent of the gross revenue from exploration and production activities of those fields as a 'Special Share tax' to finance R&D activities in Brazil. At least fifty per cent of these funds must be used to hire accredited Brazilian universities and public research institutes for R&D projects, whilst up to fifty per cent may be used internally for R&D activities in the Brazilian premises of the company, or for the hiring of other Brazilian-based companies for R&D projects. With regards to the preceding discussion of the oil sector's 'low R&D intensity', this will ensure Brazilian petroleum significantly exceeds the global average for R&D investment in the sector.

Although policy is not within the remit of this paper (a detailed examination of the Brazilian petroleum policy landscape is offered in Chapter 2), it is an important consideration in discussing the creation of the cluster. The case study companies are all first tier suppliers (i.e. companies that offer products and/or services to the oil field operators). By establishing technology centres in Brazil, they can potentially benefit from the ‘internal 50%’ generated by the 1% Regulation. Rio de Janeiro, and particularly Ilha do Fundão, offers an ideal environment for investment given the specialised knowledge base already established by CENPES and COPPE. The island offers increasing opportunities for collaboration: with the university, other suppliers, and Petrobras.

When created in 2003, the science park was envisaged as a multi-sector space to be steadily grown over twenty years. However, the pre-salt discoveries and sectoral regulatory environment lead to the rapid uptake of the land by petroleum firms. In part, the decision of which companies occupy the park is out of the hands of the university: as a public institution, the tenancy option must go through a bidding process. This was discussed with Leonardo Melo (an employee of the park’s Corporate Relations team), who stated that although “the [winner] of the bid is not necessarily the best option for [the park]”, to date they have been fortunate in the companies selected. Mauricio Guedes, the Director of the park (in May 2015), discussed the rapid emergence of the cluster: “in 2007, [with the] announcement [of] the discovery of the pre-salt reservoir in Rio, we had a boom of companies arriving, establishing research units in our park. It was faster and it was bigger than we planned”.

In discussing the future of the park, Mr Melo outlined that Ilha do Fundão is “not an oil and gas park. [...] Our challenge is how to, of course, enjoy the situation, but [also] how to diversify our portfolio to have competitive advantages in the global scenario”. The state government has acquired an additional area of 240,000 square metres on the island (previously belonging to the army) to support the expansion of the park. The park is indeed diversifying: the French cosmetics giant L’Oreal and Brazilian brewing company Ambev have opened technology centres in this additional area of the island. General Electric has established a multi-disciplinary technology centre, which will conduct R&D in oil and gas, renewable energy, healthcare, aviation and information technology (Blog do Planalto, 2015; Yoshida, 2015). Nevertheless, the park management (now led by a new Director, José Carlos Pinto) has recently affirmed that oil and gas will remain a priority for the park in the future (Brasil Energia, 2015). As the park expands, possibly diversifying into other sectors, the oil and gas cluster that has emerged in the south of Ilha do Fundão is likely to strengthen further.

Cases

MNE-1

MNE-1's newly-inaugurated technology centre in Fundão is one of the company's six 'pure research centres' in the world, the other five of which are also located in key oil and gas markets. A technology manager interviewed from the centre had taken up their role around the time of the centre's opening, having been previously based at one of the firm's other centres for many years. The research from these centres is often conducted in collaboration with universities and clients in the host location. This is driven by a desire to access world-leading expertise in technical disciplines, improve perception of clients' challenges, and open opportunities to validate research outputs in the field at an early stage of development. The firm also has several 'technology and product centres', which are more limited in scope and generally have a remit of later-stage product development for specific markets.

The interviewees emphasised that the location of the centre on the island was critical to developing technologies to address the pre-salt challenge:

“[The pre-salt] is not a common problem. [...] The fact is, this is a different formation, different logistics, different everything. You are talking about wells that are three hundred kilometres from shore, very deep, [...] a layer of salt that moves. [...] The problems are different, completely different, so you need innovation” (Interviewee-A, MNE-1).

MNE-1 has focussed on established the Fundão technology centre as the home for the company's knowledge base pertaining to the pre-salt fields: “You need a place for this knowledge to reside and this is the place. [...] If someone has a problem in the pre-salt, we want to be recognised as the centre [for a solution]” (Interviewee-A, MNE-1). Critical to the development of this specialised knowledge base is collaboration. MNE-1 has been working closely with CENPES on a large number of R&D projects since taking residency in the science park. Prior to building the centre in Fundão, a 'technological cooperative agreement' was signed between MNE-1 and Petrobras, which outlined a commitment to four multi-million US\$ projects in technical fields related to the pre-salt. The agreement remains in place to this day, with the degree of collaboration having increased considerably since it was first signed.

This is indicative of Strategy I (technology-seeking FDI in R&D) behaviour. There is an advanced knowledge base within Petrobras around the unique characteristics of the pre-salt fields, which can obviously prove extremely valuable to potential suppliers. By locating their technology centre on Fundão and working collaboratively with CENPES, MNE-1 has aligned

itself with Petrobras during the early stage of the fields' development. The company has accessed a specialised and localised knowledge base, and is benefiting from the wealth of expertise in CENPES. This close relationship ensures products and services are created so as to be effective in the pre-salt environment and in complete accordance with the needs of their client.

Proximity is, of course, an important part of this dynamic, and was discussed at length in the interview. Part of this discussion was the notion that the cluster was something of a 'neutral ground'; a place where knowledge can be exchanged between two companies operating in a notoriously secretive industry:

“[Proximity] helps, definitely. You can go to CENPES in fifteen minutes. [...] This place is becoming a 'neutral ground' because there are no operations going on here. [...] You discuss only technique” (Interviewee-A, MNE-1).

The interviewees offered a rather poetic analogy for this collaborative arrangement. In the early nineteenth century, Portuguese King Dom Joao VI engaged several leading French painters to provide an artistic education to the promising artists of Rio de Janeiro. The initiative led to the creation of some of Brazil's most treasured masterpieces. The interviewees stated that, as then, they are in Rio de Janeiro to both share their expertise within the local environment but also to learn from these exchanges.

This too can be seen in MNE-1's relationship with COPPE. As with CENPES, the location of COPPE was a key determinant in establishing a technology centre on the island. The interviewees drew parallels with another of the company's technology centres in Cambridge, Massachusetts, which is located within two subway stops of both MIT and Harvard. COPPE has been alongside CENPES at the forefront of innovation in Brazilian petroleum for over fifty years. As with CENPES, there is a high degree of localised and specialised knowledge around the Brazilian drilling environment, which of late has been increasingly focussed on the pre-salt challenge. MNE-1's technology centre actively engages with the university through a wide range of mechanisms (including fieldwork trips, co-writing papers, host lectures, delivering training, mentoring students, and providing software) to support access to this knowledge. The university has a number of specialised oil and gas laboratories (afforded to them through the 1% Regulation) that can provide tests and analysis for the company: “why should we invest in [a piece of] equipment here for a project [on which] we [would] utilise this equipment for maybe one year, two years, when we can [use] one just next door. [...] To be here and be able to use these facilities is fantastic” (Interviewee-A, MNE-1). COPPE is otherwise an excellent source of expertise when the centre is looking to hire: “this is probably one of the most tangible

benefits: people” (Interviewee-A, MNE-1). The interviewees described this relationship as an on-going and increasingly fruitful collaboration. This too is Strategy I behaviour.

Collaborations have emerged with other actors in the cluster, although to date these have been with domestic SMEs (i.e. second tier suppliers) residing either within the science park’s multi-tenant buildings or in COPPE’s business incubator, rather than with other MNEs. “We tend to focus on our core business, so we need small partners, we need collaboration. [...] It is in our interest that these start-ups grow, and if it is possible, grow towards our accepted standards” (Interviewee-A, MNE-1). However, the interviewees were optimistic that opportunities for interaction with the other MNEs in Fundão would come in time. The lack of progress in this to date was attributed to the cluster being in its infancy, with the technology centres still to find their ‘identity’ and understand their role within the broader environment.

Whilst the centre has its own remit concerning the pre-salt challenge and is benefitting from the localised expertise in the cluster, this is further supplemented by the expertise of the company’s other R&D centres: “We are one of six research centres [and we collaborate] with the other centres if we need expertise that we do not have here (Interviewee-B, MNE-1). Despite the unique technological requirements of the pre-salt, the existing global expertise base of the firm is still of considerable value here. The interviewees described a bidirectional flow of knowledge, which sees the technological advances of the Fundão centre integrated into the company’s home base (and other R&D centres):

“[The research conducted here] is mostly fed into engineering projects, or it is part of on-going research that we share with other centres” (Interviewee-B, MNE-1). [...] “We are unique [within the firm] because we are [...] close to the [unique] problem that is the pre-salt; close to a major client, Petrobras; close to a major university, that is [COPPE]” (Interviewee-A, MNE-1). [...] “We communicate quite closely with [MNE-1’s] bigger centres for trying things out with the client, as it is much easier for us. And then that can impact bigger research projects back in the US or the UK” (Interviewee-B, MNE-1). “We work only on projects that bring [...] technical advantage to our company. [...] This is our mission” (Interviewee-A, MNE-1).

Whilst the activities of the Fundão technology centre are focussed on addressing the pre-salt challenge, the company is also actively pursuing opportunities for these to benefit their operations in other territories. The interviewees affirmed that the technologies developed in Fundão could be expected to offer superior efficiency and effectiveness in other oil fields. Interviewee-A drew parallels with NASA’s Apollo programme, which overcame a technical feat of great complexity that led to the creation of many technologies that are essential to our

everyday lives. “By pursuing something aggressive[ly], a big challenge, we can [develop] other techniques that make our lives easier, more reliable and safer” (Interviewee-A, MNE-1). This is particularly important given that “the industry is no longer satisfied with minor increments in efficiency or effectiveness. [...] Today, clients are looking for ‘game change’. [...] MNE-1] too are looking for breakthrough [technologies] (Interviewee-A, MNE-1). For MNE-1, the pre-salt scenario is an ideal environment in which to generate such innovations.

Beyond this, there is a frequent exchange of personnel between the company’s technology centres. At the time of the interview, a team of thirty software engineers had recently been transferred to another R&D centre of the firm. The transfer of knowledge and expertise in this manner is indicative of Strategy III behaviour (home-base augmenting FDI in R&D and technology), although the activities of the technology centre are predominantly Strategy I (technology-seeking FDI in R&D).

Tenaris

Tenaris is a world leading manufacturer and supplier of steel pipes for clients in the petroleum and energy sectors. They have a particular expertise in manufacturing oil and gas pipes to meet the requirements of ‘extreme oil’ (e.g. ultra-deep water, arctic oil). They have industrial operations across five continents. The company’s technology centre on Ilha do Fundão (opened in early 2014 at a cost of US\$ 40 million) is the latest of five R&D centres (the others are in Japan, Argentina, Italy and Mexico). Tenaris has an established presence in Brazil across several states, where it is also engaged in other energy sectors. This is, however, the firm’s first dedicated R&D centre in the country.

The technology centre in Fundão is charged with tackling the unique technical challenges of the pre-salt environment. The extremes of temperature and pressure and corrosive environment are particularly problematic when considering pipelines. The centre is therefore focussed on research in advanced metallurgy and welding technologies, and the facility is capable of structural testing beyond that of any of the company’s other research centres. The company’s R&D Director in Brazil, Marcelo Fritz, and the centre’s Product Engineering Manager, Ronaldo Silva, were interviewed for this study.

The interviewees discussed the firm’s motivation for installing a technology centre in Fundão:

“We have a long history of contact with CENPES, with Petrobras. The opportunity to be here in Fundão is mainly to be part of ‘the team’. [...] We have different companies with different segments of the market and you can have some input from them also. And also, for sure, to be very close to the university community is very important to

having the best talents in the market. Tenaris is very [well] known in some countries but in Brazil [...] it is not one of the biggest companies, so to be part of the technology park [...] is really important” (Marcelo Fritz, Tenaris).

The latter part of this statement is indicative of the core strategy behind the investment of this centre: to gain access to new markets. The company does indeed have a long working relationship with Petrobras but of a different nature from that outlined in the MNE-1 case study. The interviewees described a more traditional client-supplier relationship, whereby the supplier captures the requirements of the client and responds accordingly in the innovation process. Proximity still plays an important role in this relationship but this encompasses less collaboration than that which exists between MNE-1 and CENPES. Petrobras is generally involved only when gathering requirements and (sometimes) in demonstrating product integrity tests. The nature of this relationship with the client, which appears to be driven chiefly by access to the market, suggests that Strategy II (home-base exploiting FDI in R&D and technology) is behind the investment.

The pre-salt challenge in the field of pipelines is not as great as in other technical fields, such as those engaged in by MNE-1. As a result, the Tenaris technology centre is focussed on the development stage of R&D: adapting the company’s existing technology base to suit the pre-salt environment (i.e. extremes of pressure and temperature, and the presence of corrosive gases). The existing knowledge base of the company is very strong in comparison to that of the host (Brazil is weak in the field of pipelines). Each of the company’s technology centres has its own specialisation in this field: “for example, in Japan we are focussing on special materials. [...] Here we are unique because we have welding technologies” (Marcelo Fritz, Tenaris). “The mixture [of expertise] is very rich and we try to make the best use of all these resources that we have available” (Ronaldo Silva, Tenaris). This specialised expertise is typically exchanged between the centres through the company’s knowledge management system.

The extent to which this technology centre is focussed on adapting an established technology base, its focus on knowledge exchange with the firm’s own technology centres (as opposed to those of other companies), and the host location’s weakness in this particular technical field, are all indicative of Strategy II. There is nevertheless evidence of other strategies in the centre’s activities. Despite having only been open for a little over one year at the time of the interview, Tenaris has been successful in establishing a relationship with COPPE. This has been largely focussed on utilising COPPE as a place to seek out talented graduates, as a source of knowledge on the complexities of the pre-salt environment, and as a reliable source for testing prospective products. Tenaris has hired several graduates from COPPE and is otherwise engaged with the

university in offering scholarships and supporting graduates in their studies. The company has also invested considerably in specialised testing equipment at COPPE. Despite the centre's focus on development-phase adaptive innovation, Tenaris does engage in some 'exploratory' research, independent of market demands, in which they engage with the university. This is an early indicator of what may become an increasing part of the centre's remit in the future: Strategy I (technology-seeking FDI in R&D) investment into potentially breakthrough technologies.

Similarly, the centre has established relationships with several other firms in the cluster, although this is still very much in its infancy. The interviewees emphasised the importance of proximity in forming and maintaining relationships with these firms and COPPE:

“We have a lot of interaction with [the other firms]. Of course, being so close to them, we are able to have a lot of discussions, we can try to build a solution [in collaboration] for a specific application. [...] One of the reasons that we are all together here is to interact and to speed up [...] our capacity to bring solutions to the market, [...] to develop new technologies. These interactions, sometimes, can really bring an innovative solution, not only because of any specific development that we are doing, but just because you are interacting: you are putting two strong companies, or three, or four [together...] and bringing their best knowledge and solutions to the discussion (Ronaldo Silva, Tenaris).

The centre is acquiring knowledge and developing technologies as a direct result of the cluster. This should be considered in the context of the company as a whole. It has already been established that the company's other locations are, for the large part, supplying this centre with its knowledge and technology bases, with the centre adapting and augmenting these in order to access a new market. However, this knowledge and technology exchange is bidirectional, with the company's other locations also benefitting from the activities of the Fundão centre. The research programme for all centres is coordinated across the company, the outputs of which are shared with, and a product of, these other locations:

“Our culture is really very collaborative with the rest of the network. [...] The exchange of information is very strong. Our products in development are global. We have only one development programme and we define each year how each centre will [contribute] to this programme. [...] We need to work together to have a final product [for] the market” (Marcelo Fritz, Tenaris).

The products developed in Fundão, although driven by the challenge of the pre-salt, are applicable to the global pipelines market: satisfying the requirements of other demanding environments (such as the Gulf of Mexico) and offering improved reliability in all fields.

“The presence here was largely influenced by the challenges that we have in the Brazilian pre-salt. [...] But, of course, what is developed here for Brazilian pre-salt serves [global applications]” (Ronaldo Silva, Tenaris). “The work is for all [of] the company. [...] Our products [developed] here will be used [...] worldwide. For sure, our main partner here is Petrobras, due to the business of oil and gas in Brazil, but now some products that we develop here [are being sold to] all regions of the world: [...] Africa, Latin America, North Sea... everywhere” (Marcelo Fritz, Tenaris).

This suggests a significant degree of Strategy III (home-base augmenting FDI in R&D and technology) activity is present in this case. The company is acquiring knowledge and developing technologies in the host location that are then shared with the company as a whole. Strategy II (home-base exploiting FDI in R&D and technology) is nevertheless dominant at this time.

However, the discussion does indicate the ways in which the technology centre’s strategy may transition in the coming years. The centre had only been operating for around one year at the time of the interview and was largely focussed on engaging with Petrobras and conducting development-stage, adaptive innovation in pursuit of the pre-salt market. Nevertheless, a considerable degree of Strategy I (technology-seeking FDI in R&D) behaviour can be observed, with Tenaris having engaged in some exploratory innovation, independent of their client’s needs. The interviewees stressed that the centre would look to broaden their product development activities to encompass early research and engineering in the future. An increase in the centre’s innovative capacity and the number and strength of collaborations in which they engage may well follow, with Strategy I activities becoming more prevalent in the future.

MNE-3

MNE-3 is a global provider of equipment and services for the oil and gas industry, with a presence in over a dozen countries. The company had several production facilities in Brazil, although this is their first R&D centre in the country. The company has several other technology centres in countries with large oil and gas markets. Upon opening the centre, the company’s President declared their intent to capture the benefits of residing within the university campus, with a particular emphasis on participating in a collaborative environment and engaging with the university in particular.

It was apparent from the interview with two of the centre's technology managers that, to date, the aspirations of the company with regards to the centre are yet to be realised. Despite achieving very impressive levels of technology development (to be discussed later in this subsection), the centre is benefitting surprisingly little from its environment. First, the centre is generally utilising COPPE only as a resource for testing, rather than as a collaborative partner:

“The best interactions [...] we have had [with COPPE] is on lab work. [...] We had some projects where we gave them the scope to do a one or two-year project [...] and that has gone nowhere. [...] Interaction with the university in terms of having a good collaboration, in terms of [...] developing [technology] – other than working with them as a lab – it is not going well (Interviewee-C, MNE-3).

Collaborative projects have not gained traction to date, which the interviewees believed was due to the university's lack of interest in engaging in such projects, or otherwise being unable to meet the demanding deadlines of the company. The interviewees affirmed that the move to Fundão had been beneficial in “forcing” the centre to interact with COPPE, as prior to that there had been “zero interaction with the university and [...] zero access and interest in working with them” (Interviewee-C, MNE-3). However, the nature of this interaction has not been as was expected when the centre was created. It was hoped COPPE would be a source of collaboration to support a strategy of ‘technology-seeking FDI in R&D’ (i.e. Strategy I), but this has not come to pass.

Similarly, MNE-3 has only engaged minimally with the other industry actors on the island. The centre has not completed any collaborative efforts with the other MNEs in the cluster, despite some clear commonality with the areas of specialism of these firms. The interviewees stated they could not imagine such arrangements even being possible due to the secretive nature of the industry (particularly amongst global leaders). They nevertheless acknowledged the benefits that could be reaped from a more collaborative scenario. The centre has also looked to engage the SMEs in the park and adjoining business incubator but did not find any areas of expertise that the company was looking to capture. However, the centre has sought collaboration and engaged with companies beyond the boundaries of the island (both within Brazil and internationally, and including university spin-offs):

“We do not have many possible partners in Brazil, [...] we need to look more globally. When we partner with companies, it is to [have] their knowledge and technology integrated into our equipment” (Interviewee-C, MNE-3). “We have access to disciplines that we are not specialists [in]. We have two hundred engineers [but] we

do not know everything. [...] Sometimes we need to go so deep into a specific subject that we need help. [...] We access those specific companies because they know more than we do and we do not have an interest in developing that as a product within [the company]" (Interviewee-D, MNE-3).

This is evidence of asset-augmenting behaviour, although unlike MNE-1, it involves collaborations with partners outside the cluster.

Within the cluster, the centre has a relationship with CENPES, where Petrobras is involved throughout the product development process. However, this was described less as a collaborative relationship and more of one based on the unidirectional exchange of information (i.e. a traditional client-supplier relationship), so as to access the Brazilian market. There is an element of Strategy II (home-base exploiting FDI in R&D and technology) behaviour to such a relationship, although this is not the dominant strategy of the centre.

The centre is developing products for global markets: "as a technology centre, we cannot look only to Brazil. We try to [consider] both: local and global. [...] The things that we are developing here that are getting more attention, they are having global impact" (Interviewee-C, MNE-3). Some products developed at the centre are not even marketable in Brazil. The centre's innovation effort is often not directed at a particular market at all, instead being driven by the promise of a certain technology or material. The technology centre operates with a high degree of autonomy from the parent organisation, although R&D activities are always focussed on providing value to the company's core business. This is reaping rewards: in an industry increasingly demanding of its suppliers with regards to cost and schedule, the centre is regularly creating technologies that offer reductions of these metrics of between thirty and fifty per cent to global clients. As such, the activities of the centre are satisfying not only the aspirations of the company for Brazil but those of the global enterprise, as is the nature of Strategy III (home-base augmenting FDI in R&D and technology) investment.

"The meaning of success for this technology centre [...] is to transfer technology. [...] By transferring technology I mean having the [company...] adopting the technology that was developed here and actually using it in products. If they think this is beneficial for them and they start adopting that technology, this is [...] the measure of success. The ultimate client for the technology centre must be the [company's] product lines that will adopt this technology" (Interviewee-C, MNE-3).

The previous two case studies have shown how a subsidiary can exist within a network of the company's other centres and home base. In the case of MNE-3, the Fundão centre has minimal interaction with the company's other technology centres, and the flow of knowledge is largely

unidirectional from the centre to the home location. Also in contrast to the first two case studies, this technology centre does not significantly benefit from being located on the island (with the exception of the ease of interaction with the client). The local benefits that were envisaged at the time of the centre's conception (in keeping with Strategy I investment) have not been realised. This has left the centre to focus increasingly on utilising its innovative capacity to address the needs of global markets, thereby augmenting the company's home-base. The decision to partner with global actors and focus on global markets protects the centre from both adverse market conditions and a lack of collaborative opportunities in the cluster. The proceeding case study illustrates that these factors can be hugely impactful on the R&D activities of a technology centre.

MNE-4

MNE-4 is a global technology leader in a diverse array of sectors: oil and gas being one of the company's key markets. As with MNE-1, a partnership with Petrobras was established prior to constructing the technology centre on Fundão. The investment was part of the company's enhanced focus on Brazil as a potential high-growth market, which also included building several production facilities in the country around the same time. As with MNE-3, at the time of the centre's creation there was a great deal of optimism conveyed by the company's executive group in media interviews and press releases around the potential locational benefits that could be sought in Fundão. The opportunities to collaborate, particularly with CENPES, were emphasised.

When visited in May 2015, the technology centre was running at around one-third of its manpower capacity, following the dismissal of several hundred of the technology centre's employees six months earlier. When originally conceived, the success of the technology centre hinged upon being able to engage with other oil companies in collaborative partnerships, particularly Petrobras: "the plan was based on fulfilling Petrobras' [...] specific requirements of the Brazilian oil field" (Interviewee-E, MNE-4). At the time of the visit, several laboratories designed to be used in support of these partnerships sat empty and unused.

Despite being open for several years, the centre has been unable to secure cooperative arrangements with the other enterprises in Fundão, and has therefore been unable to execute its desired Strategy I (technology-seeking FDI in R&D) mission: the creation of novel innovations for applications specific to the pre-salt environment (as with MNE-1). MNE-4 has not secured external investment from Petrobras' R&D expenditure commitment stipulated by the 1% Regulation, as was hoped for at the centre's conception. The interviewee stated he did not believe CENPES was engaging in any collaborative R&D projects at the time, following the

allegations of widespread corruption and bribery in Petrobras that emerged just over a year earlier.

The company has taken the decision to realign its R&D strategy in the centre, much like MNE-3 had: “[It] is difficult to survive [in this scenario]. [...] You] cannot do R&D for Petrobras, you have to do R&D for [the company]”. As this implies, the technology centre has adopted a Strategy III (home-base augmenting FDI in R&D and technology) approach, where the centre’s client is effectively the global operations of the company. The centre has carved out a specialisation within the company in certain technical disciplines, with a particular focus on the testing and piloting of innovations. Products enter the technology centre at an early stage of development and leave at a more advanced stage, having benefitted from the expertise therein. This expertise is augmented by the local environment, although this is limited to the involvement of COPPE:

“Since we do not have any [of our] own R&D projects here, we are bringing R&D projects from our headquarters to Brazil. [...] The company uses Brazil as a source of resources. [...] We are doing these R&D projects with the university [...] but only for specific projects. Not every R&D project can be run here in Brazil [for the global market]. Therefore, we select what we could do [...] at the university and we select the ones which [have] more affinity with what we can do here (Interviewee-E, MNE-4).

Contrary to the experiences of MNE-3, this centre has successfully partnered with the university under a collaborative arrangement. The interviewee emphasised the pivotal role the university plays in supporting the development of products for the global market. As the centre is currently operating below capacity, the projects with COPPE are led by the management at the centre, with the vast share of R&D activities performed at the university. The specialised expertise at COPPE is utilised wherever possible: “we are trying to use, as much as we can, the capabilities of [...] the university” (Interviewee-E, MNE-4). The proximity to COPPE simplifies the process of interaction.

This case study highlights the extent to which a technology centre’s innovation activity (and therefore its R&D strategy) is affected by external conditions beyond its control. The Petrobras crisis (i.e. the recent corruption scandal at the company) has been hugely impactful on this technology centre. This has been more pronounced here due to the subsidiary being conceived as a collaborative space. The degree of interaction with the other technology centres on the island has also been much lower than was hoped for and the company has not engaged in any R&D projects with the other centres. The inaction of CENPES has contributed to this, given

its role as an intermediary between firms that regard themselves as competitors. The lack of R&D investment following the Petrobras crisis impacts not only on the interactions between the science park residents and CENPES but also between the residents themselves. The management of the science park are actively trying to increase the level of interaction between the technology centres (the mechanisms for which are outlined in Chapter 3). MNE-4 has been involved in this process, and the interviewee was optimistic that this will improve considerably in the future (along with the status of CENPES as an innovative agent on the island).

MNE-5

An interview was conducted at a fifth technology centre (MNE-5). The primary motive for the creation of the centre was to benefit from Petrobras' 1% Regulation commitment in partnering with CENPES: "We are here because we had an opportunity to use part of that fund in our activities" (Interviewee-F, MNE-5). The mission of the centre was to work closely with both CENPES and COPPE to create technologies specifically for the pre-salt environment, with long-term prospects of transferring those technologies for use in similar oil fields (such as West Africa, should such reserves be proven in the future). Although a cooperative agreement was signed with Petrobras prior to opening the technology centre, this has only resulted in one collaborative project to date. The agreement was renewed in September 2014 but without any budgetary allocation. Relations have halted between the companies, with internal funding for R&D activities subsequently withdrawn by MNE-5: "What changed over these years is [that it has become] very difficult to get funding from the customers, so most of the projects were funded directly by [the company]. [...] Suddenly [MNE-5] took the decision to cut resources here and give another direction to the centre. [...] It is on hold right now because of the situation with Petrobras" (Interviewee-F, MNE-5). The centre has enjoyed a good relationship with COPPE, including working collaboratively on several projects, although this too has stalled given the lack of investment in R&D projects.

As with MNE-4, the technology centre's aim to carry out a Strategy I (technology-seeking FDI in R&D) approach to its innovative activities has been impacted by a lack of external investment. However, in this case, the centre has been unable to adapt its R&D strategy in response to this and was not conducting any R&D activity at the time of the interview. The 5000m² centre, which cost US\$ 50 million, was staffed by fewer than ten people at the time of the interview, with most of the centre's staff either made redundant or transferred to other subsidiaries of the firm (the interviewee was, in fact, only days from relocating to Houston). Thus, the centre's level of operations is unlikely to recover in the near future. The centre's downfall was attributed to the crisis at Petrobras, the considerable fall in the crude oil price (which halved between July 2014 and December 2015) and the extent to which the centre had

failed to secure investment from operators through the 1% Regulation. On this latter point in particular, the interviewee expressed strong opinions, stating that the design of the 1% Regulation was a leading contributor to the centre's demise and a change thereof was the centre's best opportunity for recovery:

“That [regulation] is a disaster as it is right now. [...] Nobody is happy. The universities are not happy, operators are not happy, and the service companies are not happy. [...] The biggest issue that we have today is the ANP [1%] regulation. It does not help us. [...] Now what we are trying to do – and not only us but also the university and the Director of the technology parks in Brazil – [...] is to [request that ANP] consider that the 0.5% that today is allocated to universities includes also the technology parks. Not only universities. [...] If they do that, [...] it is going to be a step change for us, then we are going to be successful. [...] We must get projects to survive and grow again. [...] I think we have an opportunity to do it but [...] without the means from ANP, [...] it is going to be really hard” (Interviewee-F, MNE-5).

As of May 2015, all R&D projects had been cancelled and any activity of that nature was not expected to resume until at least late-2016. As a result, a current R&D strategy for the centre cannot be discerned at this point in time.

Due to the lack of R&D activity in the centre, this case study has been discussed only briefly. Its inclusion in the paper is nevertheless important. It offers validation with regards to the findings already outlined by the preceding case studies, particularly those derived from MNE-3 and MNE-4: subsidiaries that also initially exhibited a Strategy I (technology-seeking FDI in R&D) approach. Whilst those firms responded to a lack of local collaborative opportunities by changing strategy, MNE-5 has not done so, leading to the halting of all R&D activity within the centre. This is particularly curious, given that MNE-5 has very strong links vertically through the company: “We are engaged with the [other] technology centres. We do not do anything by ourselves” (Interviewee-F, MNE-5). A strategy change to Strategy III (home-base augmenting FDI in R&D and technology) may well have been possible. The case demonstrates the consequences of a subsidiary's inability to adapt in response to changes in the cluster environment.

Analysis

The preceding discussion has shown, as earlier studies of R&D internationalisation have (e.g. Cantwell and Noonan, 2002; Criscuolo et al., 2005), that a firm may exhibit behaviours pertaining to several different strategies at any one time. A dominant strategy was nevertheless apparent in each case, with the exception of MNE-5, where no current R&D strategy was discernible. The five case studies and key findings thereof are presented in Table 7.

Table 7: Summary table of the case studies

Case study	Current strategy dimensions		Current strategy	Initial strategy	Notes on strategy change
	MNE parent technological advantage	Asset-exploiting/asset-augmenting strategy of MNE subsidiary			
MNE-1	Weak with regards to pre-salt and ultra-deep water exploration and production, which is the primary focus of the technology centre and a localised strength of Fundão.	Asset-augmenting: high levels of collaboration with Petrobras and COPPE (which were key locational determinants); collaboration with clustered SMEs.	S1 Technology-seeking FDI in R&D	S1 Technology-seeking FDI in R&D	N/A

Tenaris	Strong, insofar as the company's existing knowledge and technology bases are largely suitable to pre-salt and ultra-deep water production.	Asset-exploiting: market-focussed; R&D is development-focussed and of an adaptive nature; client-supplier relationship with Petrobras; low levels of localised collaboration (although increasing); utilising parent knowledge and technology bases.	S2 Home-base exploiting FDI in R&D and technology	S2 Home-base exploiting FDI in R&D and technology	N/A
MNE-3	Strong: the technology centre is currently focussed on global markets and the company's existing competencies, rather than accessing local markets or localised knowledge bases.	Asset-augmenting: high levels of R&D (inc. significant exploratory research); low levels of localised collaboration but considerable collaborative efforts with extra-cluster actors; vertical integration and technology transfer through the firm.	S3 Home-base augmenting FDI in R&D and technology	S1 Technology-seeking FDI in R&D	Technology centre was created to capture localised knowledge base through collaboration (with COPPE in particular); collaborative opportunities were not as anticipated, which led to strategy change.
MNE-4	Strong: focussed on pursuing technological advantages already held by the parent firm.	Asset-augmenting: technology-driven, with an established specialism in certain technical fields;	S3 Home-base augmenting FDI in R&D and technology	S1 Technology-seeking FDI in R&D	Technology centre was conceived as a collaborative space; potential of partnering with Petrobras was major locational determinant (collaborative arrangement was

		vertical integration (parent firm is the client); collaboration with firm's other technology centres and COPPE.			signed; potential of 1% Regulation investment); Petrobras crisis has been particularly impactful; now operating at one-third capacity due to a lack of collaborative opportunities.
MNE-5	N/A	N/A	N/A	S1 Technology-seeking FDI in R&D	Initial strategy was focussed primarily on collaborating with Petrobras (hopeful of 1% Regulation financing; cooperative arrangement in place); lack of funding from operators (attributed to Petrobras crisis and 1% Regulation design) has led parent firm to halt all R&D activity; no current R&D strategy could be discerned.

The strategies of the case study firms are mapped onto the research framework in Figure 14 below. This diagram shows both the current and initial strategies for the respective technology centres, which are located on the diagram with regards to both the dominant strategy and any secondary strategies.

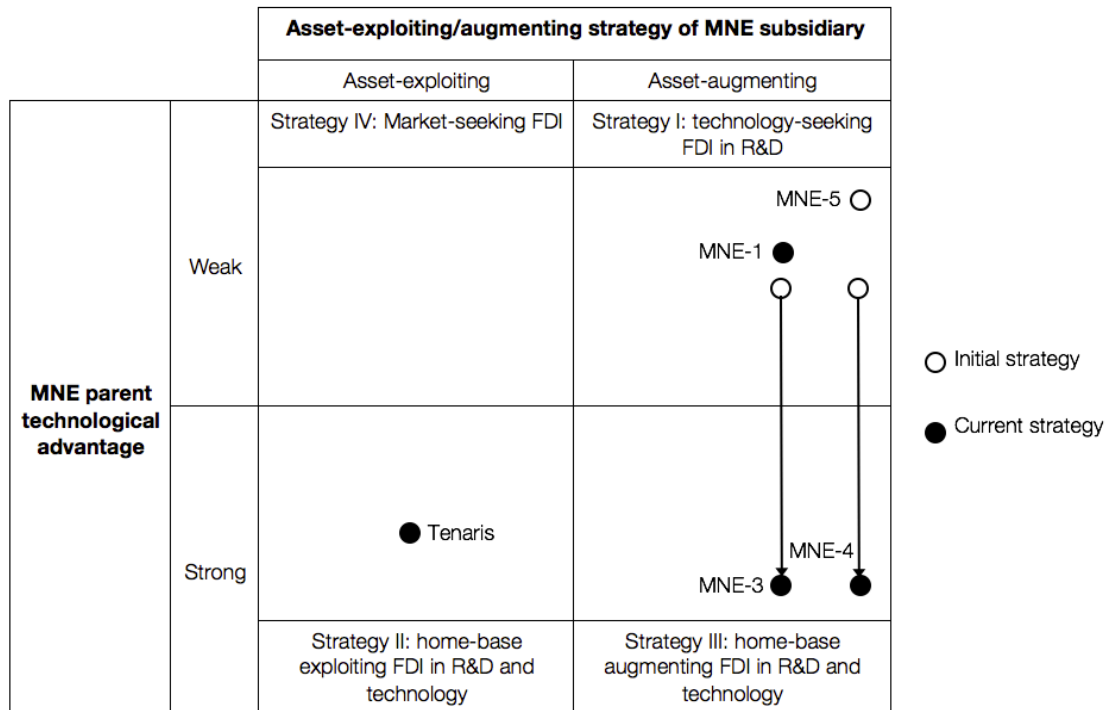


Figure 14: R&D internationalisation strategies of clustered foreign subsidiaries on Ilha do Fundão

Four of the five technology centres examined here were established with a Strategy I (technology-seeking FDI in R&D) objective. Each of these subsidiaries were inaugurated with a mission to collaborate with local agents, thereby contributing to, and learning from, the specialised local knowledge base that has been developed by CENPES and COPPE over the last fifty years. With respect to MNE-1, MNE-4 and MNE-5, this was driven in particular by the intention to establish collaborative linkages with Petrobras: working with their principal client in developing specialised equipment and services for the pre-salt. Two of these firms signed collaborative agreements with Petrobras prior to founding their Fundão technology centres. The arrangement between MNE-1 and Petrobras has been extremely fruitful, leading to a large number of R&D projects and aligning the supplier with the client in the early stages of the pre-salt development. The arrangement between MNE-5 has been ineffectual, leading to only one project to date. Whilst MNE-5 and MNE-4 were particularly hopeful of securing investment for R&D projects through the 1% Regulation, opportunities are not currently forthcoming. Elsewhere, MNE-3 attested that the location of the technology centre was driven by a desire to participate in what was anticipated to be a thriving collaborative environment,

with particular emphasis on engaging with COPPE. This aspiration too has not been met. In fact, it appears that only the expectations for the cluster of MNE-1 have been met at present.

The prevalence of asset-augmenting strategies (Strategy I and Strategy III) is in accordance with the first hypothesis of the paper. The literature emphasises the presence of locational advantages in clusters, and the agglomeration of firms to capture these is in accordance with asset-augmenting strategies. The prevalence of Strategy I as an initial strategy amongst the case study subsidiaries is equally understandable given the unique nature of the pre-salt: many technical disciplines require significant levels of technology development, and many firms will be innovating from a position of relatively weak technological advantage. Several of the hosted firms expressed a confidence that the technologies developed on the island would have applications beyond Brazil. However, the principle driver for the initial investment in the four asset-augmenting cases was to capture the specific requirements for the pre-salt fields, and to work collaboratively to develop novel innovations to satisfy these requirements.

The composition and location of the Fundão cluster offers several further advantages to those firms seeking collaborative opportunities. First, the relationship between COPPE and CENPES is cemented on the island, offering a specialised knowledge base on the unique characteristics of the pre-salt fields and other deep and ultra-deep water environments. Secondly, this relationship has established a culture of knowledge exchange on the island, albeit between a firm and a university, which is different to a client-supplier relationship, and different again from that which occurs between competitors. Several of the hosted firms are hoping that this relationship can be expanded to a collaborative network between numerous actors on the island. The sheer concentration of firms (along with the vast campus of the university), isolated from the rest of the city, and all within walking distance from one another, is another attractive characteristic. Also, every company in the science park and business incubator share an infrastructure away from the rest of the campus, which itself has proven conducive to establishing relationships between firms (detailed further in Chapter 3). Finally, the uniqueness of the pre-salt with respect to many technical disciplines in oil and gas means that there truly is no other location in the world that is comparable with regards to knowledge and expertise around the reserves. Despite the current problems, Fundão will, for the foreseeable future, remain the home of research and development in sub-salt exploration and production.

Tenaris was the only case study of the five to employ an asset-exploiting strategy. The mission of the technology centre is primarily driven by access to markets: capturing requirements from the client so that products and services will be of a specification befitting those requirements. The relationship with the client is less collaborative in nature and is focussed more on information exchange than knowledge exchange. The cluster nevertheless supports such a

relationship: as Porter (1998) affirmed, clusters are a source of localised information and a conduit for the rapid perception of new market needs. However, some of the further advantages of clusters – such as technological and knowledge spillovers – cannot be observed in this case to a significant degree. This suggests that although clusters have benefits to those firms seeking to employ asset-exploiting strategies, these benefits are not as pronounced as they potentially can be to those exhibiting asset-augmenting strategies. This is evidenced most clearly in contrasting the Tenaris case with that of MNE-1. In the case of the latter, knowledge exchange is prevalent between client and supplier, and the technology centre is otherwise cooperating with many other actors on the island (both domestic SMEs and COPPE) to a considerable degree.

Given that Strategy II (home-base exploiting FDI in R&D and technology) is characterised by a strong corporate technological advantage against a comparably weak host location specialism, it is somewhat surprising to find such a strategy in a cluster. Tenaris is currently focussed on adapting its established technology base to the pre-salt: a less challenging prospect in the field of pipelines when contrasted with many other technical disciplines. As such, knowledge exchange is far more evident in intra-firm linkages than with the cluster's other actors. However, although not a primary mission of the centre at present, Tenaris has begun to exhibit some asset-augmenting behaviour: instigating discussions with the other clustered firms, which may lead to collaborations, as well as some initial exploratory research with the university. This implies that, even in those cases where asset-augmenting R&D activities are not the primary mission of a subsidiary, the lure of broader locational benefits (namely, collaboration and knowledge exchange) can lead firms to incorporate such activities into their scope of work over time.

This brings us to a discussion of strategy change. Two of the five case studies (MNE-3 and MNE-4) were observed to have realigned their R&D strategies over the last two years: from Strategy I (technology-seeking FDI in R&D) to Strategy III (home-base augmenting FDI in R&D and technology). This is still asset-augmenting behaviour. However, rather than being focussed on the host country market, innovation activities are instead directed towards augmenting existing competitive advantages for global markets. MNE-3 and MNE-4 have changed their strategy due to a combination of factors related to both the current state of the domestic market and the collaborative environment within the cluster (which are, in part, related). This was described by one interviewee as 'a perfect storm': the drastic drop in the crude oil price, the crisis at Petrobras, and the lack of investment for suppliers through the 1% Regulation.

All five of the case study technology centres were created at a time that could be considered an industry 'boom', with a high crude oil price and tremendous optimism around the potential of the pre-salt fields. At that time, leaders of all four of the asset-augmenting technology centres affirmed their intention to capture locational benefits through collaborative arrangements with the island's other actors. MNE-1 and MNE-5 went so far as to sign collaborative agreements with Petrobras prior to inauguration.

A second hypothesis was put forward that stated the level of R&D activity and productivity of those actors exhibiting asset-augmenting strategies would be adversely affected by a negative change in the cluster environment. Whilst several factors have contributed to a negative change in the cluster environment, this has had a varying effect on those firms employing asset-augmenting strategies. For MNE-1, the cluster environment has not changed considerably, and the subsidiary has been able to maintain and even strengthen their linkages with local actors during this turbulent time. Conversely, MNE-5 has been greatly impacted by the changes to the environment, which has resulted in a dearth of collaborative and funding opportunities for the subsidiary. Further, and to varying degrees of success, MNE-3 and MNE-4 have addressed a negative change in the cluster environment by altering R&D strategy so as to focus on intra-firm and extra-cluster linkages. This change of strategy was born of necessity: "one of the reasons we look for global reach in the things that we do is [...] for survival" (Interviewee-C, MNE-3). Interestingly, in the case of MNE-4, the pivotal collaborative partner in this renewed strategy is local: COPPE. As such, although Strategy III is not dependent on Porter's locational benefits, it is compatible with them.

Thus, of the two asset-augmenting strategies, Strategy I (technology-seeking FDI in R&D) is dependent on locational advantages, given that it is driven by a desire to capture a localised knowledge base that is not currently a strength of the parent firm. Conversely, the other technology-driven strategy, Strategy III (home-base augmenting FDI in R&D and technology), is focussed on enhancing the existing technological advantages of the company. Consequently, where access to a cluster's localised knowledge base is not granted, or such locational advantages are otherwise unavailable, subsidiaries can direct their R&D activities to global markets through intra-firm linkages and partnering with extra-cluster actors in locations where augmenting knowledge bases reside.

There is still the question of why MNE-1 and Tenaris have been unaffected by this 'perfect storm' of external factors. In the case of Tenaris, the technology centre is driven by a strategy that is not reliant upon the presence of locational benefits, nor the involvement of the lead actor, Petrobras, beyond that of a typical client-supplier relationship. The centre has been somewhat protected from the changes in the industry and cluster dynamics and has maintained its focus

on a Strategy II approach. MNE-1 has been successful in securing locational advantages despite the industrial turbulence, which has included many collaborative projects with the actors on Fundão. This may best be attributed to the company's size and standing in the industry, especially in comparison to MNE-4 and MNE-5 in particular. MNE-1 is an industry giant, with a collaborative relationship with Petrobras that spans several decades. It is also not reliant on external funding in the manner in which MNE-4 and MNE-5 are, with a significantly higher R&D expenditure than any of the other case study firms.

The leading assertion of this study was that the R&D activities of the hosted subsidiaries would be impacted by the cluster environment. Ultimately, different subsidiaries will be affected to differing degrees. In turn, the cluster environment and availability of locational advantages has been shaped, in part, by the recent macroeconomic instability of Brazil. The significance of macroeconomic stability to clusters was previously affirmed by Porter (1998). However, this can be extended to also include 'sectoral stability', which, has been observed here to have a considerable influence on the presence of knowledge exchange and collaboration in a cluster. Were it not for these external factors, the capturing of locational benefits would still be far from assured, especially considering the cluster's youth and the secretive nature of the petroleum industry. Nevertheless, the analysis here indicates that macroeconomic, political and sectoral instability can be extremely detrimental to the knowledge flow, collaborative opportunities and investment climate in a cluster.

In Brazil, the current global instability of the sector is exacerbated by the crisis at Petrobras. The corruption scandal has significantly impacted the investment landscape in Brazilian petroleum. In the years following the discovery of the pre-salt reserves, the company embarked upon the largest corporate capital expenditure programme in the world (Leahy, 2015). Following the corruption scandal, the firm's investment budget was reduced from US\$207 billion for the period of 2014 to 2018 to US\$130 billion for 2015 to 2019 (ibid). The interviewees from MNE-4 and MNE-5 attested to the impact this has had on the funding opportunities for firms in the cluster, thus highlighting the crucial role of Petrobras. The notion of the 'leader' firm as a driver for innovation in clusters has been described before in the literature (e.g. Matlay and Mitra, 2006). This is evident on Fundão, in which the actors are reliant upon Petrobras as an agent for innovation. A lack of collaborative engagement from an actor as pivotal as Petrobras ultimately leads to fewer collaborations between the lead firm and the other actors. Further, this leads to fewer interactions amongst the other actors. This is of concern not only to the firms on the island but also to Petrobras' long-time collaborator, COPPE. The university's aspirations for the science park are not currently being met, as fewer

interactions between the actors ultimately results in fewer and less innovative projects for themselves.

The science park on Ilha do Fundão should still be considered a success in some regards. The level of investment already committed to the island is very impressive: US\$ 250 million in technology centres and US\$ 50 million across over three hundred R&D projects with the university (Brasil Energia, 2015). This is particularly noteworthy given the cluster's age and that this investment has been made in a developing country under a scenario of great technological uncertainty. The study captures a uniquely problematic moment for the Brazilian oil industry. However, large-scale investment from MNEs on Fundão has nevertheless been forthcoming and is set to continue. There is great potential for the cluster, especially in light of the science park management's declaration that oil and gas will remain a priority for the island (ibid). A greater concentration of firms (including domestic SMEs) and an increase in external investment (following a resolution of the crisis at Petrobras) would create the opportunity for more innovation, more collaboration, and ultimately the consolidation of a highly specialised and valuable knowledge base on Fundão.

Conclusions

In examining the R&D investment strategies of foreign subsidiaries in a specific location, this study has highlighted the insights that can be gleaned from not generalising the strategies and underlying motives behind the innovation-focussed FDI of multinational enterprises. Many preceding studies have taken a generalised view on the R&D activities of MNEs in foreign locations. This research demonstrates that it is very possible to discern distinct strategies from clustered subsidiaries, and that significant findings can be reached in doing so. As such, this paper is a starting point for further research into the relationship between the R&D internationalisation strategies of multinational firms and the local environment (that being either an industry cluster or regional innovation system).

The four-strategy taxonomy has proven useful in analysing the strategies of these subsidiaries, despite emerging from broader patent-based studies of R&D internationalisation. The research framework has allowed for the discernment between two different asset-augmenting strategies, which may have otherwise been missed under the classic asset-augmenting/asset-exploiting dichotomy. In-depth interviews have been effective in providing a comprehensive data source for analysis, offering a more holistic perspective on R&D-focussed FDI, and capturing not only the changes in a subsidiary's strategy over time but also the motives behind this change. Whereas the literature is extensive in the subjects of both corporate R&D internationalisation and industrial clusters, typical studies of R&D-focussed FDI fail to capture the nuances of the

individual subsidiaries and their environment in the manner that has been achieved here. By isolating the innovation activities of specific technology centres, the study has arrived at conclusions that would not have otherwise been attainable.

With regards to the paper's theoretical and empirical insights, it is helpful to refer back to the hypotheses presented in discussion of the research framework. The first of these stated that the majority of the case study subsidiaries would exhibit asset-augmenting R&D strategies. This has been substantiated in the finding that four of the five case studies were employing such strategies. An increasing propensity for asset-augmenting R&D in foreign subsidiaries has been observed in the literature previously. This has been explained through several factors: the increasing expense and complexity of R&D; the faster rate of technological development in many industries; and incentivisation from governmental intervention (Narula and Zanfei, 2005). These together lead firms to pursue collaborative opportunities with actors in selected geographically-dispersed locations in order access specialised knowledge bases. This can further be explained in this study by the nature of locational advantages in clusters and how these align with asset-augmenting R&D strategies (particularly Strategy I). It is therefore suggested that the pervasiveness of asset-augmenting R&D behaviour in this study can be found in many other industry clusters. This is a matter for future investigation.

Further to the prevalence of asset-augmenting strategies in clusters is the finding that, in locations possessing both a unique knowledge base and a valuable market, firms will favour Strategy I at the time of a subsidiary's creation. The primary focus of the subsidiary will be to establish collaborative arrangements with local actors and centralise the R&D activities within the cluster. However, such an approach is dependent on the availability of collaborative opportunities. This can therefore be considered to be something of a risky endeavour. Firms must be aware of this dependency on locational benefits and be either assured of attaining access to them or otherwise be prepared, and have the capacity, to change strategy. In cases where locational benefits are unattainable, Strategy III (home-base augmenting FDI in R&D in technology) is the logical and seemingly preferred alternative, whereby a subsidiary can still pursue the collaborative opportunities that are present in the cluster, without a dependency on such arrangements to pursue local markets.

The second hypothesis stated that the productivity and level of R&D activity of those subsidiaries exhibiting asset-augmenting strategies would be adversely affected by a negative change in the cluster environment. Previous studies have found that the cluster environment strongly influences the innovation performance of clustered firms (Furman et al., 2002). However, there is evidence that a subsidiary can maintain its innovation performance under a scenario of diminished collaborative opportunities if the firm is able to adapt and realign its

R&D strategy accordingly. Therefore, we can say that the cluster environment impacts upon the *focus* of R&D activities (as best illustrated by the strong innovation performance achieved by MNE-3 by altering its R&D strategy) but not necessarily the *level* of R&D performance.

The analysis has highlighted that the current turmoil in Brazilian petroleum has had a profound effect on both the level of innovation activity and the focus of that activity on Fundão. The significance of macroeconomic and political stability to industry clusters is emphasised in the literature (e.g. Porter, 1998), yet the case study evidence here also highlights the importance of *sectoral* stability to the cluster environment and, by extension, the availability of collaboration and investment opportunities for the actors therein. This sectoral stability can be affected by both national (e.g. the Petrobras crisis) and global (e.g. the oil price crash) dynamics. Whilst perhaps the risk of such shocks is most prominent in energy markets, all industries are vulnerable to sector shocks of this nature. The recent history of Ilha do Fundão illustrates how clusters can be formed from an industry boom but conversely how industry shocks can greatly disrupt them.

The study has important implications for policymakers. The presence of MNEs in clusters and the existence of cooperation between them and local actors is an important knowledge source for developing countries (Archibugi et al., 1999) and complements the pursuit of indigenous innovation (Fu et al., 2011). Relationships between local firms and MNEs can lead to the absorption of new technological competencies, which may lead to domestic firms becoming global suppliers themselves in the long-term. How to stimulate close relationships between domestic firms and MNEs is one of the leading challenges of cluster policy intervention. The Brazilian government has not had a significant direct involvement in the cluster's development, although the 1% Regulation has certainly played a role in shaping the interactions between many of the actors on the island. The current lack of interaction within the cluster suggests governmental intervention may be needed to support technology transfer and knowledge exchange therein. This could be direct intervention (i.e. incentivising and/or funding collaborative projects between localised actors), or may otherwise be addressed through a reconfiguration of the 1% Regulation (as suggested by Interviewee-F of MNE-5) so as to fund the R&D activities of private enterprises within university science parks. However, the latter could prove detrimental to co-located SMEs in science parks with a considerable number of MNEs (such as Fundão), as the reputation of the MNEs would surely make them the more attractive investment for operators. Besides considerations of indigenous innovation, improving interaction in Fundão is otherwise key to further maintaining Rio de Janeiro as a world-leading knowledge and technology base for deep and ultra-deep water technologies.

In formulating cluster policies, it is important that governing bodies understand the strategies outlined in this paper. They must decide which strategies they wish to attract to the cluster and incentivise these accordingly. They must also evaluate which strategies they expect to be employed by resident firms, in consideration of the knowledge and technology bases that already reside in the cluster. If the explicit goal of the cluster is R&D and indigenous innovation, the literature underlines the importance of interaction between clustered actors. This should therefore be a pivotal focus of any intervention. Indigenous innovation will benefit more from asset-augmenting (i.e. technology-driven) strategies, where the R&D intensity of such activities is higher, and the opportunities for technological spillovers and knowledge exchange amongst co-located actors are greater. The right governmental incentives can both increase interactions between firms and also steer them towards a more collaborative, asset-augmenting mode.

At the same time, just as a clustered firm's strategy for a technology centre can be hampered by political, macroeconomic and sectoral instability, so too can the government's goals for the cluster. If the state is to play an active role in shaping the development of a cluster, it must understand the ways in which it can be impacted by external factors. Attempting to rectify a stagnating or declining cluster *ex tempore* during times of instability will prove very challenging, so it is important that contingency plans are developed that address how best to restore the cluster to a strong position under such circumstances.

The findings also have several significant implications for practitioners. First, with regards to the clustered firms, the study underlines the need for subsidiaries (and their parent firms) to anticipate and identify changes in the cluster environment. The analysis has revealed that subsidiaries adopting different R&D strategies have differing susceptibility to changes in the cluster conditions (and, by extension, political, macroeconomic and sectoral instability). Subsidiaries adopting Strategy I are more reliant on the presence of locational advantages and the ability to capture them, since such firms are driven by the pursuit of a localised knowledge base. These subsidiaries are more likely to be affected by changes in the cluster environment, and the ability to anticipate and identify these changes is all the more important.

Equally, once a change in the environment occurs, subsidiaries must also develop the capacity to respond accordingly. Where this investment is predicated on access to local knowledge bases but such benefits are not available (even in the short-term), the firm still has options with regards to the strategic direction the subsidiary can take, so as to remain operational. The ability of subsidiaries to reposition themselves strategically in the absence of locational benefits can therefore prove decisive, particularly during periods of national and sectoral instability. The effectiveness with which two of the case studies (MNE-3 and MNE-4) were able to change

strategy in this manner is demonstrative of this point. This shows that an asset-augmenting strategy can be maintained during negative changes in the cluster environment through the pursuit of extra-cluster and intra-firm collaborative linkages. It is assumed that once macroeconomic and, particularly, sectoral stability is restored, these technology centres will be equally capable of strategically repositioning themselves so as to focus once again on local markets and collaborating with local agents. Conversely, subsidiaries adopting an asset-exploiting strategy will be less susceptible to a changing cluster environment, as they are less focussed on collaborative engagement and knowledge exchange. This may be an alternative approach. Just as the locational advantages of clusters are less pronounced in asset-exploiting subsidiaries, so too is the exposure to external shocks.

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Chapter 5: Conclusions

This chapter concludes the thesis. Later subsections of the chapter will reflect on the changing landscape of the Brazilian economic and political systems and national oil industry since the period of fieldwork study, as well as discussing the limitations of the research, the contributions of the thesis, and opportunities for further investigation. First, however, this subsection offers an overview of the thesis.

The thesis examines the role of three pivotal tenets of a well-functioning innovation system: an effective system of institutional and governance structures; a network of higher education institutes as a source of knowledge and technology generation; and the presence and R&D-focused investment of collaboratively-engaged foreign MNEs. These have each been addressed in turn in the preceding three chapters of the thesis.

Chapter 2 discusses the relationship between co-existing national and sectoral systems of innovation, with a particular focus on the role of national government as an actor that traverses both systems. The paper underlines the challenge governments face in reconciling the often conflicting policy demands of these systems of innovation, and the need for policy measures across co-existing systems to be formulated in consideration of this dynamic.

Chapter 3 examines the changing role of entrepreneurial universities in innovation systems, and the diverse and far-reaching mechanisms that this encompasses. This includes the involvement of a greater number of actors and stakeholders, an increased significance of entrepreneurship education, and more opportunities for students to create viable businesses whilst still undergoing their education. Socioeconomic advancement is also revealed to be a key driver of this endeavour. Governments are implored to support academic entrepreneurship efforts of this kind, although with the caveat that such support should not constrain the university in designing an entrepreneurial university model to best suit its environment.

Finally, Chapter 4 addresses the ways in which the conditions of an industry cluster (i.e. the presence of cooperative opportunities amongst the localised actors) affect the R&D internationalisation strategies of resident MNE subsidiaries. Among other conclusions, the paper affirms the significant impact changing cluster conditions have, although this is shown to affect the R&D focus of foreign MNE subsidiaries but not necessarily their level of output. In turn, the cluster environment is shown to be negatively affected by macroeconomic, political and sectoral instability. A firm's capacity to anticipate changes in the cluster environment and adapt its R&D strategy accordingly can prove decisive. Further, policymakers and science park managers should determine which strategies they wish to attract from resident firms and

incentivise desirable behaviours from them (e.g. knowledge exchange, collaboration and technology transfer).

For ease of reference, summaries of the research approach and key findings of each paper can be found in the tables below.

An overview of the research aims, focus, methods and data sources of the three papers is shown in Table 8.

Table 8: Summary table of papers – research aims, focus, methods and data sources

Title	Research Aims	Research Focus	Research Methods and Data Sources
Paper 1 (Chapter 2): The dual roles of government in national and sectoral systems of innovation: policy design and application in Brazil's oil and gas sector	To examine the relationship between national and sectoral systems of innovation, particularly the role of government therein as an actor that traverses both systems.	A comparative case study analysis between the policy decisions of Norway during the North Sea oil development of the 1970s with those of Brazil following the pre-salt discoveries.	The Brazil case is formed predominantly from semi-structured interviews with a diverse set of actors. The Norwegian case is informed by documentary analysis.
Paper 2 (Chapter 3): Emerging models of the entrepreneurial university: lessons from Brazil	To determine what are the mechanisms, roles, drivers and outputs that comprise the emerging entrepreneurial model, and further, what implications this model has for Brazil and other developing countries.	A theory building case study approach to establish a framework for capturing the emerging entrepreneurial university model.	Semi-structured interviews with both the coordinators (universities, science parks and incubators) and beneficiaries (domestic SMEs) of academic entrepreneurship initiatives.
Paper 3 (Chapter 4): The R&D internationalisation strategies of clustered multinational firms on Brazil's 'Oil Island'	To investigate how the cluster environment impacts upon the R&D strategies of foreign MNE subsidiaries, and how changing cluster conditions lead these subsidiaries to alter their R&D strategies.	A theory testing approach, adapting the framework of Le Bas and Sierra (2002) for a qualitative study and capturing dynamic variables.	Semi-structured interviews with the technology managers of five foreign MNE subsidiaries located in the UFRJ science park.

An overview of the key findings for researchers, practitioners and policymakers from the three papers is offered in Table 9.

Table 9: Summary table of papers – insights for researchers, practitioners and policymakers

Title	Conceptual Insights	Insights for Practitioners/Policymakers
<p>Paper 1 (Chapter 2): The dual roles of government in national and sectoral systems of innovation: policy design and application in Brazil's oil and gas sector</p>	<p>National and sectoral systems of innovation have distinct and not necessarily complementary policy demands. They do not co-exist with one another effortlessly, and complementarity between them is not assured;</p> <p>Conflicts can arise between the competing policy demands of national and sectoral systems of innovation. If not resolved, it can negatively affect the domestic innovation performance of one or both systems;</p> <p>Political and economic contexts matter in determining the innovation pathways of countries and national industries, although this requires further investigation to substantiate.</p>	<p>Policy plays a pivotal role in shaping the NSI-SSI intersection;</p> <p>The reconciling of two co-existing systems' policy demands requires the deployment of well-considered policy interventions;</p> <p>Policies designed to promote an SSI in a country should be intertwined and, most importantly, coordinated with those enacted in the NSI;</p> <p>Each NSI-SSI configuration is unique and, as such, policy imitation (a common course of action for developing countries) will often struggle to achieve reconciliation of conflicting policy demands.</p>
<p>Paper 2 (Chapter 3): Emerging models of the entrepreneurial university: lessons from Brazil</p>	<p>Academic entrepreneurship can be an explicit mission of universities;</p> <p>Universities are evolving in their academic entrepreneurship efforts into a much broader and far-reaching set of initiatives, which incorporate a greater number of actors and stakeholders,</p>	<p>Additional/adapted metrics are required by which to measure success in entrepreneurial universities. Similarly, prestige should be attributed by the academic community and broader society to those universities that succeed in an academic entrepreneurship mission;</p> <p>Developing country governments should strive to find a balance between the facilitation of academic entrepreneurship</p>

	<p>under a remit of socioeconomic betterment in addition to considerations of revenue generation;</p> <p>Entrepreneurship education is of increasing importance to academic entrepreneurship and is an area for future research.</p>	<p>and granting universities the freedom to develop their own models thereof to best suit their environment.</p>
<p>Paper 3 (Chapter 4): The R&D internationalisation strategies of clustered multinational firms on Brazil's 'Oil Island'</p>	<p>Asset-augmenting strategies are prevalent amongst clustered foreign MNE subsidiaries;</p> <p>The cluster environment impacts upon the focus of R&D activities but not necessarily the level of R&D performance;</p> <p>Macroeconomic, political <i>and</i> sectoral instability all affect the cluster environment.</p>	<p>Firms exhibiting asset-augmenting strategies are more reliant on the presence of locational advantages, or the ability to capture them. These subsidiaries are thus more likely to be affected by changes in the cluster environment;</p> <p>Firms and their subsidiaries must build the capacity to anticipate and identify changes in the cluster environment, and be able to change their R&D strategy accordingly;</p> <p>Policymakers (and science park managers) should understand these strategies, determine which they wish to attract to the cluster, and which they are likely to attract given the cluster's knowledge/technology specialism;</p> <p>Policymakers have an important role in incentivising and otherwise encouraging knowledge exchange, technology transfer and collaboration between clustered actors.</p>

Post-fieldwork reflections on Brazil and its petroleum industry

The findings of the study are temporally bounded by the three fieldwork periods. The landscape of the Brazilian economic and political systems, the country's oil industry and the global oil sector changed considerably during the period of study, and has also shifted significantly since. Over the last five years, Brazil's initially strong economic growth gave way to steady decline (annual GDP % growth rates of 7.5 in 2010, 3.9 in 2011, 1.9 in 2012, 3.0 in 2013 and 0.1 in 2014; OECD, 2015). Whilst this decline was at first in keeping with a general contraction in OECD country economies, it has worsened in the last two years, bringing the country into recession in mid-2015. This recession has deepened as of mid-2016 – the country's worst for twenty-five years – and Brazil is facing the prospect of an even steeper contraction in the latter half of the year (Biller, 2016).

The economic slump has been attributed to a multitude of global and national factors but amongst them are two that have been discussed in this thesis, and have worsened since completion of the data collection phase of the study. For much of the first half of the period of study, the Brent crude oil price remained within a range of US\$90 and US\$120, as it had since the first quarter of 2011. In mid-2014, just after the time of the second fieldwork visit to Brazil, prices began to fall. This was due to a reduction in demand in the developing world and an increase in production in the United States, leading to an oil glut. This oversupply has continued to drive the oil price down to the extent that, in January 2016, the price sank below US\$30: a reduction of 75 per cent in less than two years. Given the significance of petroleum to the Brazilian economy, this is a major contributor to the country's economic downturn.

What is surprising is the lack of effect this has had on the pre-salt development. In response to questions over the viability of the pre-salt reserves under this very different price scenario, in December 2014 the Director General of ANP, Magda Chambriard, declared that pre-salt oil was profitable “even at [the] sixty dollar mark” (Tovar, 2014). Only a month later, Petrobras declared the break-even price of pre-salt production to be US\$45 (World Oil, 2015). As of July 2016, oil prices have recovered from a low of US\$28 in January 2016 to around US\$45. Throughout the oil price turmoil, development of the pre-salt fields has remained on track, with production even rising six per cent between January and February 2016 (Forte, 2016).

Another significant factor in the economic contraction is the corruption scandal that has gripped the country. This too is strongly tied to the oil industry and, particularly, Petrobras. In 2014, Operation Lava Jato revealed the country's largest corruption scandal (not insignificant, given that Brazil has long been plagued by corruption), which has implicated several of the country's

highest government officials in corruption and money laundering allegations that involve the misappropriation of billions of dollars via Petrobras. This includes President Rousseff's predecessor, Lula Inácio Lula da Silva, whose inauguration as President was once heralded as the end of corruption in Brazil (Flynn, 2005). President Rousseff, who was on the Petrobras board of directors between 2003 and 2010 when most of the corruption allegations are said to have occurred, is, as of July 2016, facing impeachment proceedings over charges of manipulating government accounts.

The combination of the scandal and oil price downturn has led Petrobras to considerably constrain its investment strategy. In January 2016, Petrobras' five-year investment plan (for the period 2015-19) was cut to US\$98 billion: a reduction of twenty five per cent from the original forecast of US\$130 billion (Pearson, 2016). As Brazil's single largest source of investment (the company's capital expenditures accounted for nearly 8 per cent of total investment in 2014; Kiernan, 2015), this will have a profound effect on those sectors that rely on Petrobras' demand for equipment and services. Further, it suggests indigenous innovation (both within the firm and within the national industry) will also suffer as the company resolves its internal issues and awaits an oil price recovery that would raise income from its operations. Given the firm's pivotal role within the sectoral system of innovation, a lower level of investment and fewer collaborative opportunities can be expected for domestic firms. The nature of spillover effects across sectors for indigenous innovation also suggests that this will have repercussions for the broader national system of innovation also.

The Petrobras crisis and oil price crash has also had a significant impact on another crucial component of indigenous innovation: R&D-focussed FDI. As was highlighted in the introductory chapter of the thesis, Brazil has a long history of dependency on FDI as the primary source of technology transfer. Under the current scenario, Brazil is an unattractive prospect for foreign investment. A recent report from management consultancy A.T. Kearney identified the economic downturn and current business environment in Brazil as explanatory factors for a 12 per cent drop in FDI inflows in 2015 compared with the previous year (Rapoza, 2016). The third paper illustrates how a lower level of investment from foreign MNEs is associated with lower levels of collaboration with domestic actors. Such a scenario ultimately limits the opportunities for technology transfer between foreign MNEs and domestic firms and universities, thus again impacting indigenous innovation performance.

There is a further recent development associated with the national oil industry that is also likely to have repercussions for indigenous innovation. This, however, particularly concerns the national system of innovation. In 2015, 25 per cent of the Ministry of Science's projected budget was cut, leaving a funding climate that is "the worst in twenty years", according to

Helena Nader, president of the Brazilian Society for the Advancement of Science (SBPC; Escobar, 2015). When Petrobras' monopoly was broken in 1997, a stipulation was made that royalties from the country's oil fields be used to fund national science and technology projects. As recently as 2013, this amounted to an investment of US\$600 million to the National Fund for Scientific and Technological Development (FNDCT), which is the primary source of funding for innovation in Brazil (Escobar, 2015). Over the last two years, the government has redirected much of these funds, once intended to fund research, to other areas such as public education and health. FNDCT is coordinated by FINEP (Financier of Studies and Projects) and one interviewee from FINEP, Rogério Medeiros, raised this as a concern in April 2014. Brazil's main funding agency, the National Council for Scientific and Technological Development (CNPq), received just 27 per cent of the US\$350 million it was expecting in 2014 (ibid).

This highlights how indigenous innovation can be constrained by an economic downturn. This is in part due to changing industry dynamics, where key actors (both domestic and foreign) commit a lower level of R&D investment, which reduces collaboration and technology transfer opportunities for domestic firms and universities/research institutes. A shift in governmental priorities can also be observed in this case, and this too has impacted the environment for indigenous innovation. The first paper concludes that Brazil has a tendency to prioritise the policy demands of the broader population when faced with an innovation opportunity, thereby stifling the innovation activities of domestic industries. It would seem that national technological progress can also be sacrificed in order to address the country's need for investment in social services, such as education and healthcare, during challenging times. This is short-sighted given the significance of innovation to economic progress (refer Chapter 1).

Whilst a recent survey (April 2016) of Brazil analysts has forecasted growth for the country of 0.4 per cent in 2017 (Biller, 2016), there is call for concern given the extent to which innovation efforts have been constrained in the recent economic environment. A very modest growth rate is unlikely to see significant changes to either the inflow of FDI, nor the structure of government funding for science and technology. Further, once the Brazilian economy is on the road to recovery, what damage may have been done to the country's innovative capacity? Several years of reduced funding for research may leave Brazil behind the curve with regards to innovation in several of its core industries. The fallout from the economic downturn may continue to inhibit innovation efforts long after it has ended, thus constraining Brazil's pursuit of catch-up.

One of the leading assumptions behind the forecasted economic growth in Brazil in 2017 is that President Rousseff's assumed successor, current Vice President Michel Temer, will turn to

market-friendly measures to generate growth (Biller, 2016). One significant market-friendly measure has already been passed this year. Since 2010, Petrobras has held a monopoly as the only operator permitted in the pre-salt fields, as underwritten by law. A bill was passed in February 2016 that opens the fields again to an auction process, albeit with the government maintaining the right to offer Petrobras first refusal on future oil field developments. Some might say that the country's current macroeconomic scenario, combined with the ongoing scandal at Petrobras and the company's ballooning debt (in excess of US\$130 billion), left the government with little choice. Resource nationalism is seemingly no longer viable in the current climate. This may signal that the government is preparing to abandon its protectionist approach to the industry, as it did in bringing an end to the previous protectionist regime that had proven detrimental to the country's innovative capacity (refer Chapter 2).

The ending of the Petrobras monopoly in the short-term, and prospect of more market-friendly measures in the industry in the long-term, are promising for indigenous innovation. Opening the market will invite a higher level of FDI over the coming years. If such measures are successful, this will spill over into collaboration and technology transfer opportunities for domestic firms. It will also increase the number of technology sources and the depth of expertise from which Brazilian industry can learn, which increases the potential of spillovers into other industries.

Despite the recent 12 per cent downturn in national FDI inflows, foreign investment has nevertheless been forthcoming under the pre-salt scenario in Brazilian petroleum. This is evident in the UFRJ science park and establishment of technology centres of global petroleum MNEs (albeit some of which are currently operating at a reduced capacity). As discussed in Chapter 1, Brazil has consistently sought FDI as its primary source of technology transfer. The evidence presented in this thesis (particularly in Chapters 2 and 4) suggest this is destined to remain the leading source of innovation in the country. Although some research suggests that emerging economies are looking beyond a typical model of FDI for innovation (i.e. a trade market for technology policy; Fu and Gong, 2011; Tang and Hussler, 2011), there is little evidence of such a transition in Brazil.

The literature tells us that indigenous innovation requires a balance between incentivising FDI and supporting the innovative activities of domestic firms (Fu et al., 2011). Brazil is seemingly yet to find this balance. Chapter 2 highlights the shortcomings of the current policy offering (along with the funding-related concerns addressed in this chapter) in fostering domestic innovation. This highlights the need for an effective system of institutional and governance structures (both sectoral and national) in the pursuit of indigenous innovation, and the urgency with which these shortcomings in Brazil should be addressed. Further, whilst these weaknesses

endure, and the balance between foreign and domestic sources of innovation is amiss, Brazil's economic recovery is likely to be hampered and, long-term, the country will be unsuccessful in its pursuit of catch-up.

Limitations of the research

The empirical research conducted for this study should be considered within the context of several limitations, which will be outlined here. The first comes to light particularly given the preceding discussion of changing industrial and economic dynamics. Given the scope of this doctoral study, it was necessary to conduct research over three fieldwork visits. This is in one regard a strength, whereby the changing dynamics of the industry and national economy, and how these impact upon the system of innovation, are captured. From another perspective, however, this is a limitation, in two respects. First, these changing dynamics mean that the data collected from one interview subject in April 2014 may be very different from that which would have been collected if they had been interviewed in May 2015. Certain key actors interviewed in 2014 were interviewed again in 2015 with the objective of capturing these changes. Secondly, these dynamics have continued to change since completion of the fieldwork, and thus there is a further limitation with regards to the currency of the data also. Documentary research subsequent to the final fieldwork period has ensured that technical details concerning the industry's regulatory and funding landscape in particular are accurate at the time of publication. A limitation such as this is inevitable with case study research and does not lessen the relevance of the conclusions drawn in each paper.

Another limitation concerns the spatial boundary of the thesis. Four cities within three Brazilian states were visited for fieldwork purposes. Upon reflection, these were the best locations for fieldwork, although it is regrettable that the police strike in Salvador halted research efforts there. However, one limitation of the completed framework presented in Chapter 3 is that it is not derived from a large number of case study universities. As this was a theory building exercise, additional case studies in other Brazilian cities and states may have identified further mechanisms used to promote technology transfer and academic entrepreneurship. This can be considered an area for future research, to be explored not only within Brazil but also other developing and developed economies.

With regards to the interviews themselves, there are two further limitations of the study. First, it is regrettable that an interview with a representative from ANP could not be secured in 2015, despite the best efforts of the researcher. Whereas the interview in 2014 had a largely exploratory focus, a further interview in 2015 – especially given the changes in the industry that had occurred over the preceding twelve months – could have added explanatory detail

around the relevant policy decisions. This may have added clarification as to the underlying motives behind these decisions and the intentions of the government with regards to the future of the industry. This could have also further substantiated the conflict between innovation systems that is discussed in the Chapter 2. Similarly, it is also regrettable that interviews with the MNEs discussed in Chapter 4 could not be secured in 2014, with the exception of one (MNE-3 in that paper), again despite the best efforts of the researcher at the time. The focus of the paper is the changing R&D strategies of foreign MNE subsidiaries in light of shifting external conditions: conditions which changed considerably between April 2014 and May 2015. The findings of the paper could have been enriched with a discussion of how individual subsidiaries' R&D strategies had changed between fieldwork visits.

Finally, despite the shortcomings of patent data in addressing 'how' and 'why' questions, such as those posed by this thesis, if the time had been available to use patent analysis in a mixed methods approach, this would have supported some of the findings of the papers. Given the significance of collaboration highlighted in each paper, patent data would ideally have been used to create a social network of collaborators (domestic and international firms, and public universities and research institutes) within the innovation system. This could further have been used to identify both potential interview subjects and areas for discussion for particular interviews, and thereafter in enriching some of the research findings. However, time constraints being as they were during the period of study, the inclusion of patent data as a data source was not possible.

Contributions of the thesis

This thesis has made several contributions to the existing body of literature. First, the systemic perspective of indigenous innovation presented here – as analysed through the systems of innovation theory – reveals the role of several groups of diverse actors, the significance of interactions between these actors, and the importance of a supportive institutional framework. By examining three pivot tenets of an effective system of innovation, the thesis highlights the role of each group of actors in the system, and the specific challenges faced by each in fostering innovation. Whilst several studies have examined the challenge of pursuing indigenous innovation in emerging economies, the focus has primarily been on that driven by domestic MNEs, as opposed to domestic SMEs and universities. This is one of the first attempts at a comprehensive analysis of an emerging economy system of innovation, which includes important findings that can guide emerging economies and other developing countries.

The analysis has shown the significance of emerging economies' macroeconomic conditions to the pursuit of innovation. Over the period of study, these conditions changed a great deal in

the case study country. These changing conditions exposed weaknesses in the innovation system that may have been less pronounced during times of economic prosperity. Most notably, the pursuit of innovation was downgraded as a priority and, in some regards, was abandoned in an attempt to address the economic downturn. Industrial sectors can be manipulated as a tool for national policymaking, so as to address the needs of the country's broader population during such challenging times. Macroeconomic, political and sectoral instability are all observed to negatively affect indigenous innovation.

Thirdly, it offers a conceptualisation of the relationship between national and sectoral systems of innovation. Few studies of innovation examine this at two levels of analysis, as was the focus of Chapter 2. The paper reveals the often incompatible policy demands of co-existing innovation systems, and the challenge of national government in achieving the reconciliation of these demands, so as to support indigenous innovation (both sectoral and national) and macroeconomic betterment. It also underlines the extent of this challenge in developing countries, where the policy demands of the national system may be more compelling. It is a useful framework for policymakers and a basis for further applications and development from other researchers.

Fourthly, a timely perspective has been offered on the changing nature of academic entrepreneurship. Just as other researchers have noted an emerging evolution in the role universities play in society, the same can be equally observed in *entrepreneurial* universities. Universities are seen to demonstrate strategic planning and highly-effective decision-making in delivering their entrepreneurial mission through a broad and far-reaching array of initiatives. This challenges the traditional notion that universities are knowledge suppliers and such entrepreneurial endeavours cannot be an explicit mission of these institutions. The analysis is accompanied by a resource-based stage gate model that can form the basis for evaluation across different models of entrepreneurial university.

Finally, the thesis contributes to a better understanding of the R&D strategies of foreign MNE subsidiaries in clusters. The cluster environment can be both inhibitive and supportive to those firms pursuing innovation, and particularly collaboration, within such an environment. It highlights the importance of foreign firms being cognisant of how their environment might change and the need to develop contingencies for alternative R&D strategies, depending on how the environment changes. Further, the framework offered in the paper, although developed so as to support the analysis of a cluster environment, is nevertheless equally valuable in examining the R&D strategies of foreign subsidiaries in any environment, and can be used with qualitative, quantitative or mixed methods approaches.

Opportunities for future research

The findings of the thesis present several opportunities for future research. First, the study of indigenous innovation in emerging economies through the systems of innovation perspective has offered several interesting findings, as discussed above. However, it is important that this is explored further in other emerging economies, especially where the case study sector and country are not undergoing such a tumultuous period. Here, this led to significant findings concerning the influence negative political, economic and industrial conditions play in shaping the dynamic between national and sectoral systems of innovation. However, this should be further explored in industries/countries enjoying economic and political stability. There will also almost certainly be examples of emerging economies that have effectively reconciled the policy demands of co-existing sectoral and national systems of innovation. This would also capture other factors underpinning different industry dynamics, governmental frameworks, knowledge, technology and expertise bases, and different economic and sectoral pressures. The systems of innovation theory would again prove ideal for such an investigation. This would bring an assurance of ‘generalisability’ to certain findings in the thesis where this has not yet been achieved.

The analysis in Chapter 3 offers a framework of university-led academic entrepreneurship and technology transfer mechanisms, based on a single case study country (and from several universities therein). This framework is designed to be applicable across all economic contexts, despite the developing country focus of the paper. The framework should be used as the basis for future investigation into further emerging models of entrepreneurial university in other countries and economic contexts.

Finally, Chapter 4’s adaptation of an existing framework for measuring changes in foreign firm R&D strategies also offers opportunities for future research with regards to both the research methodology and scope of focus. This revised framework allows for a dynamic analysis of how R&D strategies change over time. This has only been utilised in a single cluster setting and there are further insights to be gained from exploring other contexts, thus inviting a broader discussion of the relationship between the R&D strategies of foreign firms and their environment. With regards to the methodology, this framework has also demonstrated a flexibility with regards to the data sources used. Adopting the use of quantitative methods (such as patent analysis, bibliometrics, or web mining) as part of a mixed methods approach would add a further level of contextual insight: the ‘who’ in addition to the ‘how’ and ‘why’.


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Appendices

Appendix 1: Participation Information Sheet



The University of Manchester
Manchester Business School

NB: the information described in this template should be adapted, where necessary, for children, adults with learning difficulties or non-English language speakers. If applicable, alternative means of providing the same information through a different medium should be described.

Transforming innovation systems in emerging economies: an evolutionary study of the Brazilian petroleum industry

Participant Information Sheet

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Please ask if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

Who will conduct the research?

Mr Alec Waterworth, Manchester Business School, Booth St W, Manchester, M15 6PB

Title of the Research

Transforming innovation systems in emerging economies: an evolutionary study of the Brazilian petroleum industry

What is the aim of the research?

Three research questions are posed by the study:

1. How does government participate in national and sectoral systems of innovation?
2. What is the role of universities in sectoral systems of innovation (from knowledge supplier to collaborative partner)?
3. How has the involvement of domestic and international firms shaped a regional system of innovation?

Why have I been chosen?

You have been selected as a firm, government agent, research centre employee, business intermediary or academic researcher exploring technology opportunities in the petroleum industry.

What would I be asked to do if I took part?

The participant will be interviewed and asked to please answer the questions posed by researcher, in anyway they see fit, and to complete the ethical approval form when requested. The participant is under no obligation to answer any of these questions and may call a halt to the interview at any time.

What happens to the data collected?

The responses will be analysed and used to demonstrate trends and/or novel findings of the activities of innovative firms in the petroleum industry.

How is confidentiality maintained?

Where indicated on the ethical approval form, a guarantee of confidentiality is offered by the researcher. You have my assurances that the data pertaining to this research will be stored in a secure manner. Any audio recordings will be destroyed upon completion of the research (End 2015).

What happens if I do not want to take part or if I change my mind?

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time without giving a reason and without detriment to yourself.

Will I be paid for participating in the research?

You will not be paid for participating in the research. Your participation however is much appreciated by the researcher.

What is the duration of the research?

A single interview of around 2 hours.

Where will the research be conducted?

At the organisation's premises.

Will the outcomes of the research be published?

The findings of the research may be used in academic journal papers. The request for confidentiality (where indicated) will be honoured.

Contact for further information


Please contact Alec Waterworth:
T: +44 (0) 7713251038
E: alec.waterworth@postrad.mbs.ac.uk

What if something goes wrong?

Please contact Alec Waterworth:
T: +44 (0) 7713251038
E: alec.waterworth@postrad.mbs.ac.uk

If a participant wants to make a formal complaint about the conduct of the research they should contact the Head of the Research Office, Christie Building, University of Manchester, Oxford Road, Manchester, M13 9PL.

Appendix 2: Consent Form

The University of Manchester			
	<i>Transforming innovation systems in emerging economies: an evolutionary study of the Brazilian petroleum industry</i>		
	CONSENT FORM		
	If you are happy to participate please complete and sign the consent form below		
			Please Initial Box
1. I confirm that I have read the attached information sheet on the above project and have had the opportunity to consider the information and ask questions and had these answered satisfactorily.		<input type="checkbox"/>	
2. I understand that my participation in the study is voluntary and that I am free to withdraw at any time without giving a reason and without detriment to any treatment/service		<input type="checkbox"/>	
3. I consent to the audio recording of the interview for transcription purposes		<input type="checkbox"/>	
4. I consent to my name and organisation to be made public		<input type="checkbox"/>	
I agree to take part in the above project			
Name of participant	Date	Signature	
_____	_____	_____	
Name of person taking consent	Date	Signature	
_____	_____	_____	

Appendix 3: List of Interviewees

Name	Organisation	Type	City	Month-Year/Date
Neuman Solange de Resende	COPPE	Academic	Rio de Janeiro	May 2013
Sérgio Alvaro de Souza	COPPE	Academic	Rio de Janeiro	May 2013
[Anonymous]	COPPE	Academic	Rio de Janeiro	May 2013
Wilsa Atella	Ambidados	SME	Rio de Janeiro	April 2014
Carlos Leonardo, Beatriz Mattos	Ambipetro	SME	Rio de Janeiro	April 2014
Daniel Camerini	Ativatec	SME	Rio de Janeiro	April 2014
Carlos Eduardo Fontes	ESSS	SME	Rio de Janeiro	April 2014
Cíntia Soares	Oil Finder	SME	Rio de Janeiro	April 2014
Josias Silva	Petrec	SME	Rio de Janeiro	April 2014
Fábio Barcia	Polinova	SME	Rio de Janeiro	April 2014
[Anonymous]	SME-1	SME	Rio de Janeiro	April 2014
[Anonymous]	Petrobras	MNE	Rio de Janeiro	April 2014
Interviewee-C, Interviewee-D	MNE-3	MNE	Rio de Janeiro	April 2014
Leonardo Melo	UFRJ Science Park	Academic	Rio de Janeiro	April 2014
Lucimar Dantas	COPPE Incubator	Academic	Rio de Janeiro	April 2014
Elias Ramos de Souza	ANP	Government	Rio de Janeiro	April 2014
Rogério Amaury de Medeiros	FINEP	Government	Rio de Janeiro	April 2014
Carlos Camerini	ONIP	Non-gov	Rio de Janeiro	April 2014
[Anonymous]	COPPE	Academic	Rio de Janeiro	April 2014
Adilson de Oliveira	UFRJ	Academic	Rio de Janeiro	April 2014
[Anonymous]	SME-2	SME	Sao Paulo	April 2014
Fabiano Rampazzo	Technomar	SME	Sao Paulo	April 2014
Kazuo Nishimoto	USP-TPN/ Technomar	Academic	Sao Paulo	April 2014
[Anonymous]	USP	Academic	Sao Paulo	April 2014
[Anonymous]	USP	Academic	Sao Paulo	April 2014
Guilherme Daniel Avansi	InReservoir	SME	Campinas	April 2014

Samuel Tocalino	Adest	SME	Campinas	April 2014
Gustavo Longhin	Simworx	SME	Campinas	April 2014
Osmar Roberto Bagnato	LNLS	Academic	Campinas	April 2014
[Anonymous]	UNICAMP	Academic	Campinas	April 2014
Andre Furtado	UNICAMP	Academic	Campinas	April 2014
Interviewee-A, Interviewee-B	MNE-1	MNE	Rio de Janeiro	May 2015
Marcelo Fritz, Ronaldo Silva	Tenaris	MNE	Rio de Janeiro	May 2015
Interviewee-C	MNE-3	MNE	Rio de Janeiro	May 2015
Interviewee-E	MNE-4	MNE	Rio de Janeiro	May 2015
Interviewee-F	MNE-5	MNE	Rio de Janeiro	May 2015
[Anonymous]	MNE-6	MNE	Rio de Janeiro	May 2015
[Anonymous]	MNE-7	MNE	Rio de Janeiro	May 2015
[Anonymous]	MNE-8	MNE	Rio de Janeiro	May 2015
Fabio Hochleitner	Aquamet	SME	Rio de Janeiro	May 2015
Louis-Martin Losier	Geovoxel	SME	Rio de Janeiro	May 2015
Luiz Bevilacqua	UFRJ	Academic	Rio de Janeiro	May 2015
Mauricio Guedes	UFRJ Science Park	Academic	Rio de Janeiro	May 2015
Antonio Batista, Maíra Campos	SEBRAE	Non-gov	Rio de Janeiro	May 2015
Denise Cristiano Reigada, Thais Macieira	FINEP	Government	Rio de Janeiro	May 2015