Financial Intermediation in the 21st Century: The Rise of Environmental Investing and Financial Technologies

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To Alet, the love of my life and the true environmentalist in the family.

Abstract

This thesis seeks to shed light on how the operation of financial markets is linked with environmental outcomes at the regional, national and international level, by exploring the geographical tensions between the spatiality of finance and the scale at which environment-related decision making occurs. A focus on the financial sector cannot overlook the importance of information systems and decision-making processes of financial intermediaries. Hence, a secondary aim of the thesis is to explore the geographical scope of information systems and decision-making process of financial intermediaries, including that of emerging fintech intermediaries. Finally, the thesis is also concerned with explaining the role of environmental policy on the decision making of financial intermediaries, companies and entrepreneurs alike. The four substantive chapters focus on different types of intermediaries and clients, whose geographical scope allows for the exploration of different configurations of the finance – technology – environment nexus. First, the thesis explores how fossil fuel divestment commitments and environmental policies have shaped the geography of capital flows into the oil and gas sector. I find that the total assets pledged for divestment in a given country is negatively associated with capital flows to domestic oil and gas companies, particularly when divestment is led by regional or sovereign governments. Amongst environmental policy instruments, emissions trading schemes and renewables feed-in tariffs have been most impactful in reducing oil and gas sector capital inflows. This study presents the global scope of financial markets and companies through investment banks and the oil and gas sector, which is contrasted with the limits of country level environmental policies and state intervention.

Next, I investigate how different types of environmental policies and new regional environmental knowledge affect new venture creation in green (environmental), brown (fossil fuel) and gray (unrelated to natural resources) technologies. I find that entrepreneurs perceive more stringent environmental policies as detrimental to starting a new venture, whereas the creation of new environmental knowledge in regions is highly correlated with the creation of green ventures but not fossil fuel ventures. The analysis also shows that gray entrepreneurs benefit marginally from the creation of new environmental knowledge, suggesting that entrepreneurs across sectors benefit from the implementation of eco-efficiency principles in the evaluation of new venture creation opportunities. The thesis then shifts the focus from entrepreneurs to banks, and how they can operationalise natural capital risk assessments as part of their lending processes. In this example, the lender has a national or regional investment focus, while the environmental risk for their clients can be local, regional, national or even global in nature. I build an evidence base to support natural capital risk assessment for a single sub-sector of Australian agriculture – wheat farming and shows that such an assessment is possible, with a combination of quantitative and qualitative inputs. Finally, the thesis focuses exclusively on the links between finance and technology and shows that financial technology start-up creation is positively related to regional knowledge created in the IT sector and unrelated to regional knowledge in the incumbent financial sector. On the other hand, fintech innovation by financial services incumbents occurs in regions and countries where the clients and high fee earning subsidiaries of incumbents are located, while regional IT or financial sector productivity do not seem to be important in this context. Thus, the thesis presents four different accounts of the environment-finance-technology nexus emphasising how space, place and territory shape financial flows for the low carbon transition, environmental and financial innovation, and ultimately shape the pace at which society progresses towards tackling its most pressing issues.

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1 Introduction

1.1 Introduction to research

In trying to answer the apparently simple question: “what is a financial system for?”, academics have classified the functions of finance in four major categories: the provision of a payment system, the matching of lenders with borrowers, the management of personal finances across individual lifetimes and inter-generationally and the provision of risk management services to individuals and businesses (Davis et al., 2016; Kay, 2015). Banks have provided the service of matching of lenders with borrowers since ancient times (Allen and Santomero, 1998), while other financial intermediaries across different financial systems have emerged to fill different financial services product needs (Scholtens and van Wensveen, 2000). Such is the case of pension funds and institutional investors (Clark, 2000; Clark and Monk, 2017), investment banks (Wójcik, 2012), stock exchanges (Wójcik, 2011a) or digital lending platforms (Arner et al., 2016) among others.

The “raison d'être” of these financial intermediaries and whether they act in the best interest of their clients has been challenged in the aftermath of the global financial crisis (GFC). The failures of financial intermediaries meant that some savers have been stripped of their financial assets (Clark, 2017), while many geographies and businesses that needed capital remained highly underserved. Besides the societal expectation that financial intermediaries provide different products and services related to the four broad functions of the financial system outlined above, another underlying expectation has emerged. The emerging expectation is that these intermediaries, and more broadly financial markets, facilitate the financing of new urban infrastructure, as well as the financing of projects and companies that deliver environmental and social outcomes.

This trend is deeply rooted in the post-World War II Anglo-American economies, where the state retreated from providing different forms of infrastructure, and shifting its responsibilities onto market agents and other tiers of government authority (Clark, 2000). The faith in market-based solutions has extended to address global problems including climate change, as financial institutions have become the key actors to allocate capital over the last fifty years (Knight, 2010).

To a certain extent, one can conclude that the financial sector did respond to the call to create financial instruments supporting the low carbon economy transition, given the rise of asset classes such as green bonds, fossil fuel free equity and debt indices and the rise in low carbon asset finance. Moreover, the overwhelming commitment to integrate environmental, social and governance factors in the decision making of more than 2,200 PRI signatories with over $81 trillion assets under management[1] can be interpreted that the industry is moving in the right direction.

After the GFC, the financial industry has under gone significant corporate organization, market reorientation and innovation, but has yet to reconsider its remuneration practices or meaningfully address the issue of gender inequality and lack of diversity (Wójcik and Cojoianu, 2018b). In addition, much of the retail and SME customers have remained largely underserved, which has created the opportunity for new entrants in the market. Fuelled by the experience of the recent financial crisis, as well as the advancements in the fields of data science and increased processing power, the technology sector has emerged as a worthy challenger of incumbent financial institutions (Wójcik and Cojoianu, 2018a; Haddad and Hornuf, 2018).

On the other hand, the strength of the state – finance nexus has increased after the financial crisis, particularly through the activities of central banks in both Europe and the

[1] https://www.unpri.org/pri/about-the-pri

US, the increase in compliance and risk management requirements across the sector and the furthering of state interest in financial markets through sovereign wealth funds and other government backed financial organizations.

There are also signs that governments around the world are starting to respond to the threat of widespread environmental degradation, loss of natural capital, water scarcity and loss of infrastructure due to climate change and unsustainable economic activities. The landmark Paris Agreement[2], which was ratified by 174 countries in December 2015, can be interpreted as a sign that coordinated government action is possible to tackle climate change at a global scale.

However, since Paris, global GHG emissions have yet to peak. In fact, in 2017, GHG emissions levels reached a new high of 53.5 $GtCO_2e$, which is 0.7 $GtCO_2e$ more than in 2016 (UN, 2018). Climate scientists and environmental economists argue that GHG emissions in 2030 need to be 25% or 55% lower than the 2017 figure to be able to plausibly achieve a least-cost pathway to limiting warming to 2°C or 1.5°C respectively (UN, 2018). Ultimately, society will need to reach a net-zero emissions economy if stable global temperatures are to be achieved (Matthews and Caldeira, 2008). This seems to be improbable in the near future, as sizeable fossil fuel intensive infrastructure assets which are incompatible with a 2°C world are in the planning and construction pipeline and likely to be backed by the banking sector (Davis and Socolow, 2014; Pfeiffer et al., 2018; Smith et al., 2019).

In this light, how do we reconcile the fact that while there seems to be much consensus that the financial sector should and is partly contributing to the low carbon economy, little progress can be observed at the global level? How is the operation of

[2] https://unfccc.int/process/the-paris-agreement/status-of-ratification

financial markets linked with environmental outcomes? How have emerging financial technologies changed the financial intermediation landscape?

This thesis seeks to shed light on each of these questions by exploring the geographical tensions between the spatiality of finance and the scale at which environment-related decision making occurs. A focus on the financial sector cannot overlook the importance of information systems and decision-making processes of financial intermediaries(Clark and Monk, 2017). Hence, a secondary aim of the thesis is to explore the geographical scope of information systems and decision-making process of financial intermediaries, including that of emerging fintech intermediaries. Finally, the thesis is also concerned with explaining the role of environmental policy on the decision making of financial intermediaries, companies and entrepreneurs alike.

These themes are integrated throughout the thesis in the following way: in Chapter 3, I explore how the geography of global finance influences the funding of emission intensive industries. I do so by illustrating the link between global investment banks and oil and gas companies across 33 countries and between 2000 – 2015. I also show how oil and gas fundraising is influenced by country level environmental policy and emerging anti-fossil fuel norms. In Chapter 4, the thesis looks beyond the country level, by highlighting how availability of finance, environmental knowledge and environmental policy shapes regional start-up creation in environmentally sustainable as well as emission intensive industries. This analysis is carried out across 293 OECD regions between 2001 and 2013. The decision-making processes and information systems of financial intermediaries in the environmental context is then explored in Chapter 5. Here, I look at how the credit risk management process of lenders can be enhanced with environmental and natural capital datasets, in a case study on Australian agriculture. In this context, I explore how the availability and applicability of environmental data at

different geographical scales (on farm, regional or national) can aid lenders in making sounder decisions in both the short and long term. Last but not least, in Chapter 6, the thesis focuses on the geographical scope of technological innovations in the incumbent financial sector as well as in the emerging fintech start-up ecosystem, and the likely changes in financial intermediation as seen through the lens of regional technology cluster evolution. The broad scope of the issue is matched in this way by the broad scope of the thesis.

1.2 Theoretical framework

Historically, the underlying mechanisms which are thought to have led to the rise of different financial intermediaries throughout time are documented under the theory of financial intermediation, while the practices of intermediaries and the functioning of financial markets have fallen under the research agenda of financial economics.

Early financial intermediation theorists contended that in resource allocation models based on assumptions of perfect and complete markets, there would be no need for intermediaries (Scholtens and van Wensveen, 2000). The implications of this being that households who save a proportion of their income would need to individually manage their savings and companies that need capital to grow and expand would need to convince individual households of their credit-worthiness and crowdsource their capital. In reality, it is inefficient for households, companies or governments to individually hold savings without benefiting from the economy of scale of savings institutions (Clark, 2017). Secondly, households, individuals or organisations may wish to invest and enhance their savings to ensure their long-term welfare. Finally, potential borrowers in need of capital would have their fundraising costs significantly decreased in dealing with several intermediaries that make capital allocation decisions rather than in engaging with thousands or millions of individual savers. In this respect, transaction costs, participation

costs and asymmetric information became the reasons which scholars accepted as why financial intermediaries exist (Allen and Santomero, 1998).

But this explanation is not satisfactory when trying to answer how a pension fund is different from a commercial bank, why asset managers started to offer specialised green technology investment funds or what the drivers are behind the rise of crowdfunding platforms. In addition, this view does not explain why although transaction and information costs have decreased with the help of information technology, financial intermediation has increased after the GFC. Modern financial intermediation theorists suggest that instead of explaining trends in financial intermediation from an institutional perspective, it is more useful to think of the functional role that different financial intermediaries fulfil in the finance ecosystem. Instead of conceptualising financial institutions as operating in a static perfect market, scholars should "assume a more dynamic concept in which new markets are developed for new products, where financial institutions do not act as 'agents' who intermediate between savers and investors and thus alleviate 'market imperfections' like asymmetric information and participation costs, but are independent market parties that create financial products and whose value added to their clients is the transformation of financial risk, term, scale, location, and liquidity" (Scholtens and van Wensveen, 2000, p. 1249).

The limitation of financial intermediation theory is that it does not provide any indication about the spatial distribution of innovation in the financial intermediation chain, nor does it help explain how the spatial distribution and scale of intermediaries interacts with the spatial distribution, scale and scope of their clients. Trying to provide a unifying theory of financial intermediation, while admirable in its goal, is likely impractical given the variety of phenomena that occur in financial markets which are highly contextual across both geography and time.

In this respect, the thesis seeks to explain financial intermediation phenomena through its heterogeneity across geographies and through its observable characteristics over the last two decades. The underpinning theoretical framework I use is grounded within the fields of economic and financial geography and complemented with insights from the fields of sustainable finance and environmental economics. Financial geography is concerned with both the top-down and bottom up study of capitalism, through the decision making , social practices and geographical scope of financial institutions (Clark, 2005), whether these are institutional investors (Clark, 2000; Clark and Monk, 2017), investment banks (Wójcik, 2012), stock exchanges (Wójcik, 2011a), sovereign wealth funds (Clark et al., 2013; Monk, 2011) or new financial technologies (Arner et al., 2016; Haddad and Hornuf, 2018).

This relatively new field has emerged as a standalone branch of economic geography, which is focused on explaining the *where, why* and *how* characteristics of economic processes (Clark et al., 2018), including the role of social norms and informal institutions on economic outcomes (Cortinovis et al., 2017). In principle, financial geography would not be needed if financial economics included a robust consideration of spatiality in its explanations of how financial mechanisms work. Below, I explore different ways in which geography is relevant in the context of the operation of financial markets.

First, financial markets worldwide have had different development paths, partly due to a variety of country level pension system design choices and policies (Clark, 2000). In his 2018 American Finance Association presidential address as well as in a subsequent invited paper to the Journal of Finance, David Scharfstein shows that countries with pension policies tilted towards private pension funding are more likely to be capital markets oriented, while countries with pay-as-you-go pension systems, where

pensions are paid from the taxes of current workers, tend to be more bank focused. This has implications on the size of companies across countries, their funding sources and ownership structure (capital markets vs. bank funded) as well as the asset allocation of households, which tend to hold more housing equity in countries with pay-as-you-go pension systems (Scharfstein, 2018). There are many other institutional considerations which are impacting the form and function of financial markets worldwide, including the geography of investment regulation or that of corporate governance (Clark and Wójcik, 2007; La Porta et al., 2000). In this respect, the characteristics of country and regional level financial markets are likely to impact the way green infrastructure is financed across geographies, as well as the nature and focus of new financial technologies that either build upon or seek to disrupt current ones. Hence, in Chapters 3 and 6, the thesis explores in depth the links between country and regional financial markets and financial intermediation and their impacts on the fundraising ability of the oil and gas sector (Chapter 3) and the development of new financial technologies (Chapter 6). The country level institutional context is further analysed through the lens of environmental policy and its impacts on both environmental entrepreneurship (Chapter 4) and oil and gas financing (Chapter 3).

Another way in which geography interacts with the world of finance, is through the geographical heterogeneity embedded in information that is at the core of financial decision making (Clark and Monk, 2017). Classical financial economics states that "a market is efficient with respect to information set θ_t, if it is impossible to make economic profits by trading on the basis of information set θ_t" (Jensen, 1978, p. 96). In the same paper where he reviews the early evidence against the efficient market hypothesis (EMH) and states that the theory has strong evidence behind it, Jensen (1978) also admits that the availability of better and more granular datasets, as well as the increase in

sophistication of research methods is likely to point towards further inconsistencies in the theory. Environmental risk datasets are an example of datasets that historically have not been incorporated in the decision-making processes of financial market participants or in the pricing of most products and services. Hence, environmental issues have been seen for long as externalities (Stern, 2007). However, over the past two decades, given the steady increase in the stringency of environmental regulation across the world, the anticipated physical impacts of climate change, legal implications and low carbon economy transition risks (Carney, 2015), the financial sector has started to realize the benefits of incorporated environmental information in their decision-making processes.

It is not surprising that numerous studies and meta-studies now confirm that in many contexts, there is a positive link between environmental sustainability and corporate financial performance, which implies that those investors who are sophisticated enough to analyse environmental related datasets can reap significant benefits (Clark et al., 2014; Derwall et al., 2005; Friede et al., 2015; Hoepner, 2013; Ibikunle and Steffen, 2017). That being said, the state of awareness of environmental issues and the coverage of environmental datasets by financial institutions is highly heterogenous depending on asset class, individual environmental indicators and the geographical scale at which environmental risks or opportunities manifest themselves (Cojoianu et al., 2015). I consider these issues specifically in Chapters 3,4 and 5.

An additional dimension which has been of interest to economic and financial geographers is that of time, since the conception and execution of investment strategies are interwoven across both space and time (Clark, 2017). The notion of downside risk, understood as the product between the probability and the magnitude of an undesirable outcome, often relies on historical probabilities of observed phenomena. The time horizon of investment decisions is crucial in the context of climate change as the speed at

which the low carbon transition occurs influences climate impacts over the medium and long-term investment horizon. The difficulty in incorporating climate risk in the thinking and decisions of financial intermediaries lies mainly in the fact that climate risk is an anticipated risk whose probability and magnitude cannot be observed in historical datasets. The thesis considers the time component from multiple perspectives: the variation of environmental policy stringency across time (Chapters 3 and 4), the evolution of green and frantic technology clusters (Chapters 4 and 6) and the time horizon of climate and natural capital risks in the lending decision making context (Chapter 5).

Finally, economic geographers have been long been interested in explaining the spatiality of high-technology clusters and their evolution over time. The literature has provided ample evidence to understand new technology cluster formation including one of its most prominent determinants, the creation of new knowledge (Acs et al., 2009; Audretsch, 1995; Audretsch and Keilbach, 2007a). The thesis engages with this theme particularly throughout Chapters 4 and 6, when explaining the rise of green technologies and fintech, and briefly within Chapter 5, where the application of sensor technology to environmental credit risk management is explored.

1.3 Research objectives

The overarching objective of the thesis is to explain the spatiality of financial intermediation in the context of the emergence of environmental finance and financial technologies. This is done through the examination of financial flows, knowledge base and policy environment at the country and regional level and their implications for environmental finance. In addition, I examine the regional technological capabilities in the financial technologies space as well as how these relate to investment processes in the case of lending.

This investigation is carried out across four substantive chapters, which, although crafted individually, align with the overarching thesis objective. The thesis is comprised of an introductory chapter (Chapter 1), followed by the literature review (Chapter 2), four research articles (Chapters 3,4,5 and 6) and a concluding section (Chapter 7). The underlying research questions and overarching objectives that are explored in each chapter are outlined below.

Chapter 2 objectives

Chapter 2 outlines the different literatures which underpin the four research articles. First and foremost, I draw insights from the economic and financial geography literature regarding the geographical scope and decision-making processes of financial intermediaries. Another emerging field which has informed the research is that of sustainable finance, which deals with the integration of environmental, social and governance factors in the decision-making processes of financial intermediaries. Furthermore, sustainable finance is also concerned with new financial instruments which can foster the achievement of environmental and social outcomes, in addition to financial and economic ones. Last but not least, the literature related to the geography of innovation is a useful blueprint for understanding the likely factors influencing innovation in financial intermediaries as well as its spatial heterogeneity.

Chapter 3 objectives

Chapter 3 is titled "*The Economic Geography of Fossil Fuel Divestment, Environmental Policies and Oil and Gas Financing"*. The main research question it seeks to address is what the factors are that influence oil and gas financing across countries. I answer it by investigating closely three further sub-questions:

a) How does the geography of the investment banking sector influences and is influenced by the geography of the natural resources sector?

b) What is the role of anti-fossil fuel norms and environmental policy in shaping the financing and refinancing of oil and gas infrastructure?
c) What are the tools of government, beyond making use of classical environmental policy instruments, which can be used for the timely phaseout of fossil fuels?

This paper is currently under peer review with the *Journal of Economic Geography.* This paper is co-authored with Dr. Francisco Ascui, Prof. Gordon Clark, Prof. Andreas Hoepner and Prof. Dariusz Wójcik.

Chapter 4 objectives

Chapter 4, titled *"Going from Zero to One: How Environmental Knowledge and Policy Shapes Start-Up Creation across Green, Brown and Gray Industries"*, illustrates the factors that influence regional and country level high-growth start-up rates across 24 OECD countries and 293 regions in the period 2001-13. The underlying questions it seeks to answer are?

a) Does regional finance availability impact the emergence of new environmental and fossil fuel focused businesses?
b) Beyond financial intermediation, how does new regional environmental knowledge affect green start-up emergence?
c) Is environmental policy effective in encouraging environmental entrepreneurship?

The article is under peer review with *Research Policy (provisional outcome: Revise & Re-submit).* The article is co-authored with Prof. Gordon Clark, Prof. Andreas Hoepner, Dr. Paolo Veneri and Prof. Dariusz Wójcik.

Chapter 5 objectives

Chapter 5, titled *"Developing an evidence base for assessing natural capital risks and dependencies in lending to Australian wheat farms"*, contributes to the overall thesis by showing how geographically contextual environmental and natural capital risk factors can be integrated in the decision-making process of lenders in fragmented industries, highly dependent on natural capital, such as agriculture. The underlying research questions it seeks to answer are:

a) What are the geographical and temporal considerations inherent in analysing environmental datasets in the credit risk context? How do these apply to lending to agriculture?
b) How does the availability and complexity of datasets across different environmental indicators influence the adoption of environmental metrics in the credit risk management process of lenders?
c) Given the fragmentation of the agricultural sector worldwide, how can environmental financial products for farmers scale?

This study has been published in the *Journal of Sustainable Finance and Investment*. The article is co-authored with Dr. Francisco Ascui.

Chapter 6 objectives

Chapter 6 is concerned primarily with showcasing the geography of innovation in financial technologies, not necessarily related to the environment. The chapter is titled *"Fin vs. Tech: Fintech Start-Up Emergence and of Innovation in the Financial Services Incumbent Sector".* In this context, I investigate what influences fintech start-up emergence and fintech innovation in financial services incumbents across 21 OECD countries and 226 regions over the 2007 – 2016 period. The chapter's objective is to answer three main questions:

a) How do regional IT-related capabilities and knowledge affect the emergence of financial technology innovations in start-ups versus the financial sector incumbents?
b) How do regional finance-related capabilities and knowledge affect the emergence of financial technology innovations in start-ups versus the financial sector incumbents?
c) What are the implications on the global map of finance as a result of new financial technologies?

This paper is currently under review at the *"Small Business Economics"* journal. This paper is co-authored with Prof. Gordon Clark, Prof. Andreas Hoepner, Dr. Vladimir Pažitka and Prof. Dariusz Wójcik.

These four chapters allow me to analyze financial intermediation through both the lens of intermediaries and that of their clients, at a regional, national and international level. The choice of intermediaries is motivated by both the fact that they are underrepresented in the economic geography, financial and environmental economics literatures but also by the richness of insights these provide.

1.4 Methodology

The methodological approach of the thesis is mostly empirical for Chapters 3, 4 and 6, and qualitative, desk research based for Chapter 5. Different aspects of financial intermediation were analyzed in accordance with the most suitable research methodology given each chapter's theme. The main contributions of the thesis lie in using innovative datasets, and in some cases the first known use of some datasets in an academic setting (e.g. fossil fuel divestment commitments). In addition, the most up-to-date statistical analysis techniques are employed. Where a statistical approach would not be feasible, such as in the case of integration of natural capital risk factors in credit decision-making

models (Chapter 5), where data is highly sensitive for the banking sector and therefore hard to access, I employed a qualitative approach.

Country level panel data econometrics (Chapter 3)

The empirical set-up of Chapter 3 is tailored to analyse the impacts of environmental policy stringency and country level divestment commitments on oil and gas financing, from the perspective of both companies and their financiers, domestic and foreign investment banks. I employ a two-way log normal OLS regression model which accounts for country and year fixed effects and clusters model standard errors at both the country level and over time (Kölbel et al., 2017; Petersen, 2008). Independent variables are lagged one year. We expect the effect of divestment on financial market outcomes (e.g. oil fundraising ability or cost of capital) to be observed in the short term given that financial markets are considered complex and fast-adapting systems (Clark, 2017; Lo, 2012), particularly with respect to incorporating new financial information in investment decision making (Jensen, 1978).

The dependent variable is the annual total fundraised amount ($ million) by all oil & gas companies (public and private) in a given country and year. The financial instruments through which funds are raised in the oil & gas sector are new equity and bond issuances as well as syndicated loans from investment banks. Project finance accounts for less than 10% of new fundraising in the oil and gas sector, given the riskiness and unpredictability of such projects (EY, 2014). Hence most of the financing in the sector is reflected on the balance sheets of oil and gas companies. In this sense the results are likely to be only marginally affected by not covering the project finance asset class.

The study relies on the Dealogic database to construct a country variable of total fundraising by oil & gas companies (across equity, bond issuance and syndicated loans)

across the world. Dealogic is a global database of investment bank transactions which includes details on investment bank advisors and their clients for 673,102 fundraising deals across equity and debt issuance and syndicated loans between 2000 and 2015.

To quantify the fossil fuel divestment commitments at the country level, I benefited from the data shared by the DivestInvest initiative, an organization who tracks all the public fossil fuel divestment commitments across the world. This dataset has been cleaned and complemented with manual Internet searches with the location and assets of the organizations pledging to divest from fossil fuels. The database allows for disaggregation across organization types, hence it was possible to disentangle the influence of divestment commitments of different organization types.

The task of establishing the link between environmental policy and different economic outcomes has historically been difficult, mainly due to the unavailability of relative policy stringency measures. Scholars who sought to investigate this relationship statistically have resorted to using variables which can only provide information as to whether a policy instrument is present or not in the policy mix of a particular country, state or region, but not the degree to which these policies are stringent towards polluters or encouraging towards eco-innovators. Recent data innovations which address these issues include the work of Botta and Koźluk (2014) at the OECD, who construct environmental policy stringency indices across a wide coverage of countries and between 1990 – 2012. I use these indices as a key independent variable in this study.

Qualitative desk-based research (Chapter 5)

Chapter 5 requires a different, more qualitative approach. This study proposes to illustrate that integrating environmental factors in the lending decision making process is possible and that it can be operationalized with existing public datasets or those datasets generally available to lenders. The subsector chosen for this study is Australian

agriculture, given the high reliance of the agricultural sector on natural capital and environmental inputs as well as the relatively high availability of local and regional environment -related datasets in Australia.

However, two particular factors make it difficult to obtain the data necessary for quantitative study answering, for example, how environmental datasets impact loan default rates of farms across Australia. The first factor has to do with the fact that the loan books of commercial banks are highly sensitive information, and most banks are reluctant to sharing it. Secondly, the agricultural sector is a highly fragmented sector, with more than 85,000 farmers only in Australia, which are mostly family owned (90% of all farms worldwide are family-owned) (Graeub et al., 2016), and for which disclosure on environmental factors is very poor given that these are mainly private enterprises.

In this light, the study follows a multi-stage approach to identifying, prioritizing and researching the natural capital risks and dependencies applicable to Australian wheat farm lending, from a lender's perspective. To identify the financially material environmental and natural capital risk factors to agriculture, I use the list of 66 environmental, social and governance research providers and consultants identified by Cojoianu et al. (2015) to identify a first set of environmental risk factors applicable to agricultural lending and investing. Next, I also review 34 publications from financial institutions worldwide, publish between 2006 and 2016, to identify which natural capital risk factors financial organizations currently use in their decision-making processes.

To complement this research process, which identified broad natural capital risk factors, the study further accounts for those risk factors that are specific to Australian wheat farming. To achieve this, a triangulation exercise was carried out with evidence from three different sources: academic articles, Australian agricultural related industry

bodies (such as the Grains Research and Development Corporation, GRDC) and four interviews with Australian agribusiness, banking environmental finance professionals. For the purposes of the article I consider risk as the product of the probability of occurrence and the magnitude of impact. Hence, the financial material natural capital risk factors which have emerged range from low impact factors with high probability to high impact factors with low probability. Some risk factors have been included not because they are currently financially material to lenders, but because the factors are not currently fully priced, but have a probability of being priced in the medium to long-term. For each risk factor, the study identifies the geographical scale at which this risk becomes material, and consequently the geographical scale at which a particular risk should be analysed, and ultimately priced.

Regional level panel data econometrics (Chapter 4 and 6)

Chapters 4 and 6 propose to analyse different aspects of green finance and financial intermediation innovation through the lens of entrepreneurs and regional innovation clusters. The regional geographic scale is highly important in the study of entrepreneurship and new innovations as geographical proximity and regional characteristics have been shown to mediate both the knowledge diffusion process within and across industries as well as ultimately the entrance and growth opportunities for new ventures. Chapter 4 looks specifically at the factors related to green entrepreneurship emergence across OECD regions, focusing on the regional knowledge base and start-up capital availability, as well as with the country level environmental policy stringency impacts on green entrepreneurship. Chapter 6 on the other hand, looks at the potential impact of technology on financial intermediation by illustrating the regional indicators related to financial technology start-up emergence and regional innovation in financial services incumbents.

The two chapters use a similar empirical approach. The data is organised in a balanced panel at the TL2 regional level (OECD, 2018). The dependent variables are: new regional green and brown / fossil fuel start-ups (Chapter 4), and new regional fintech start-ups and new regional financial sector patent counts in Chapter 6. The models employed are random effects binomial models (the intercept of the regression models is allowed to vary by region) and for robustness I also cluster standard errors at the regional level (Allison and Waterman, 2002; York and Lenox, 2014). To further control for temporal variations in the models, year dummy variables are included but not reported in the results. To alleviate concerns regarding reverse causality, all regressors in the models are lagged one year for both studies. For the effect of policy on environmental entrepreneurship, we also run tests for longer lags to account the effect of policy coherence on entrepreneurship entry (Georgallis et al., 2018; Rogge and Reichardt, 2016).

In Chapter 4, the environmental entrepreneurship variable is obtained from the Crunchbase database, a leading provider of intelligence for investors in high-growth technology start-ups around the world. The same applies for regional start-up finance availability. Regional environmental knowledge is proxied by regional green patent applications. Regional green patent data was collected from the OECD REGPAT database which allows for quantification of the innovation output over more than 2,000 TL3 regions in the OECD and across several technologies including environmental technologies (Maraut et al., 2008). I aggregate these to the TL2 level to match the high-growth start-up dataset. The OECD employs robust patent search methodologies to identify all the patent applications to the EPO, USPTO and JPO as well as those filed under the Patent Cooperation Treaty (PCT)(OECD, 2016). The patents belong to six top-level environmental technology categories: i) capture, storage, sequestration or disposal

of greenhouse gases, ii) climate change mitigation technologies related to buildings, iii) climate change mitigation technologies related to energy generation, transmission or distribution, iv) climate change mitigation technologies related to transportation, v) environmental management and vi) water-related adaptation technologies (Haščič and Migotto, 2015). Finally, environmental policy stringency is measured using the OECD environmental policy stringency indices, as explained previously for Chapter 3.

In Chapter 6, regional fintech start-ups are also obtained from Crunchbase, while innovations in financial sector incumbents are proxied by new patents which were identified using the PatSeer[3] platform. A representative sample of financial services incumbents has been built, which includes the top 500 asset managers by assets under management in 2016 (Willis Towers Watson, 2017), the world's top 2000 investment and commercial banks by fees between 2000 – 2015, a list of 776 listed insurance companies which I identified by using the SASB[4] industry classification database and a list of 186 stock exchanges from around the world from Datastream (including junior stock exchanges and OTC). The commercial and investment banking dataset was built using Dealogic data and includes all banks with more than $4.8 million in total fees over the 2000 – 2015 period.

1.5 Limitations of research

The present inquiry into the geography of financial intermediation in the emerging green finance and financial technologies sectors has several limitations. These are then addressed as areas of future research in the concluding chapter (Chapter 7). Overall, Chapter 7 will also address the academic, policy and business relevant implications for

[3] www.patseer.com
[4] www.sasb.org/approach/sics

financial market design, state intervention in financial markets and implications for intermediaries and borrowers with respect to green finance and fintech.

While every effort has been made to study different phenomena at the geographical level which is deemed appropriate for each, there is a depth – breadth trade-off across each of the four substantive chapters. In analysing country levels factors which are related to oil and gas financing in Chapter 3, the study opts for a broad country coverage and hence increases the generalizability of the model. On the other hand, this approach cannot show in depth through which mechanisms fossil fuel divestments impacts individual firms or banks and how these may be different in the Anglo-American vs. continental European context for example. In studying the incorporation of natural capital risk factors in the lending decision making process, the heterogeneity of natural capital risks across different regions meant that a broad geographical coverage would be highly resource intensive. Hence, while Chapter 5 provides interesting insights, they are largely applicable only to lending to Australian agriculture, and countries that may have similar climates and agricultural sectors (e.g. South Africa). In this case, while the findings are less generalisable, the research method can be fully replicated across different countries and agricultural subsectors (Campbell, 1957; Persson and Wallin, 2015).

The four-paper approach implies that a choice had to be made as to which financial intermediaries are included (investment banks, commercial banks and fintech start-ups) as well as which of their clients are relevant to our field of enquiry (oil and gas companies, environmental and fossil fuel entrepreneurs and farmers). Research pertaining to institutional investors such as pension funds, which are highly important in the global capitalist financial system, has been left for further enquiry, although implications for them has been highlighted where possible. In Chapter 6, I seek to

highlight the innovation in the incumbent financial sector (banks, insurance companies, asset managers and stock exchanges) which partly mitigates the issue of a limited number of financial intermediaries covered.

Another limitation has to do with the ability to cover inter-related phenomena in the green finance and financial technologies space. For example, Chapter 3 studies the factors influencing the size of issuance of the oil and gas sector at the country level but is not able to cover a closely related aspect, which is the cost of capital of oil and gas companies. In Chapters 4 and 6, I study the factors related to the entrance of both green and fintech entrepreneurs, but data availability issues do not allow for the study of growth and exit. Last but not least, in Chapter 5, while I highlight the natural capital risk factors to agriculture, I am not able to test these in an empirical framework with bank loan data. I leave these for further research. The findings throughout the DPhil thesis should be interpreted as statistically robust relationships, but not as causal relationships, as I do not conduct tests that would allow for the inference of causality.

1.6 Conclusion

The advance of technology, the policy environment as well as the overarching need to realign the financial sector with societal interests have shaped both financial intermediation movements (Buchak et al., 2018; Chen et al., 2018; Criscuolo and Menon, 2015; Friede et al., 2015; Gaddy et al., 2017; Haddad and Hornuf, 2018). Trust, defined as "the expectation that another person (or institution) will perform actions that are beneficial, or at least not detrimental, to us regardless of our capacity to monitor those actions"(Sapienza and Zingales, 2012, p. 124) is a key factor underpinning economic and financial transactions (Arrow, 1972). Societal trust is relevant to the financial sector organisations for both their own operation and social license to operate, as trust in the financial sector has fallen at all times low in the aftermath of the financial crisis

(Sapienza and Zingales, 2012), as well as for financial sector investments that may lose trust of clients, suppliers and other stakeholders which can translate in losses for investors (Hoepner and Wilson, 2010). Much of the literature in sustainable finance has shown in numerous cases that incorporating social, environmental and trust factors in the investment decision making process and in the construction of new financial instruments can yield significant benefits for investors (Friede et al., 2015; Hoepner et al., 2011; Hoepner and Wilson, 2010; Ibikunle and Steffen, 2017). Environmental disasters such as the 2010 BP Deepwater Horizon oil spill and other related environment-related disasters and scandals have resulted in losses not just for the corporations involved but also for their investors whose trust has been eroded. Hence, the rise of the environmental investment, and more broadly responsible investment agenda, has unfolded as a response to better assess the environmental and social risk inherent in the investments of financial institutions, and to an extent, to respond to the societal call for the financial sector to take responsibility for environmental and social outcomes generated by their investments.

On the other hand, new financial technologies are likely to have emerged due to the erosion of trust in the financial sector , in addition to the advancements in technology which both technology incumbents and start-ups were quick to seek to capitalise on (Broström et al., 2018; Forbes, 2015; Sapienza and Zingales, 2012; Wójcik and Cojoianu, 2018b). The Financial Stability Board acknowledges that fintech solutions have penetrated market segments in which traditional banks or asset management organisations operate, but also markets of underserved customers such as "small businesses, subprime customers, and clients with insufficient credit history or lower job security" (FSB, 2019, p.12), where they have little competition. In 2017 alone, the size of the underserved financial services market amount to $173 billion (Center for Financial Services Innovation, 2017).

In this light, the thesis seeks to explain the spatiality of two modern financial intermediation phenomena: environmental investing and new financial technologies, through the interactions between and geographical scope of financial intermediaries and their clients. The thesis achieves its aim through an empirical, four paper approach inquiry, by focusing on different types of financial intermediaries and their clients, whose geographical scope allows for the exploration of different configurations of the finance – technology – environment nexus. The spatiality of environmental investing and financial technologies is explained through the lens of financial geography and the geography of innovation. In the case of environmental investing, these literatures are further complemented with insights from the fields of environmental finance and environmental policy. In the following chapters, the thesis outlines these closely related bodies of literature, then proceeds with the in-depth inquiry into the finance – technology – environment nexus through four substantive chapters (Chapters 3 to 6) and concludes with Chapter 7.

2 Literature review

2.1 Introduction

The thesis engages with bodies of literature that are closely related, in order to explain the spatial dynamics of environmental investing and financial technologies. The underlying theoretical framework is built on the geography of finance literature, a relatively new field that emerged as a branch of economic geography which is predominantly concerned with the spatial and relational dynamics of modern economic life (Clark et al., 2000). Financial geography draws on economic geography concepts and insights, but its remit has recently broadened outside the scope of economic geography given the size and growth of the modern financial sector which has come to underpin the majority of economic phenomena.

Environmental investing and new financial technologies are innovations which seek to disrupt the status quo in the financial intermediation space. In this respect, understanding these two movements through a geographically contextual innovation lens is helpful in providing further colour to the map of finance and technology. Innovation in this respect is relevant to both financial intermediaries as it is to their clients. Hence, this chapter provides an in-depth account of the literature related to innovation in both green and financial technologies.

Finally, the thesis engages with the environmental economics literature and the sustainable finance literature. The environmental economist's view, concerned with the state's intervention or lack thereof in regulating the environment, merged with the financial geographer's preoccupation of the intervention of the state in financial markets, provides a unique angle into the dynamics of the state-finance nexus and how it interacts with the environmental investing and financial technology space. On the other hand, sustainable finance has emerged as a challenge to traditional financial economic theory,

by advocating and to a large degree demonstrating that extra-financial factors (e.g. environmental, social or governance related) can enhance financial decision making if taken into consideration. It is through is diverse but closely related set of literatures that the thesis seeks to engage with the spatiality of modern financial intermediaries and their clients.

2.2 The geography of finance

The remit of financial geography is eloquently presented by Wójcik (2018) as a branch of economic geography concerned with explaining the spatial forms, structures and manifestations of finance and their determinants, as well as "[…] the consequences of the spatiality of finance for the economy, society, and [the] environment" (Wójcik, 2018, p. 557). Given that finance is an economic phenomenon, social, political and cultural factors are critical ingredients in explaining the spatiality of finance (Lee et al., 2009).

Financial and economic geographers have been long interested in understanding change processes across the economic landscape as well as more generally, describing the diversity of economic life (Clark et al., 2000). This view contrasts with financial economics theory which seeks to unveil generalizable principles and causal mechanisms across heterogenous economic and financial phenomena (Clark et al., 2000), rather than looking at financial markets as an outcome of the time varying distribution of human behaviour (Hoepner, 2016).

In this light, financial geography, concerned with both the dynamic map of finance and the change processes that underpin it, provides a useful theoretical underpinning for present thesis which seeks to explain changes in financial intermediation that come about the rise of environmental investing and financial technologies.

The insights from financial geography applicable to the thesis are abundant. The first aspect is that proximity matters in an investment context, as the literature has documented the home bias of investors in international markets, as well as the local bias of domestic investors (Coval and Moskowitz, 1999). Scholars have suggested that this occurs due to information asymmetries mediated by the distance between different investors and their investee companies. Indeed, in a follow-up study, Coval and Moskowitz (2001) show that asset managers earn substantial returns in their nearby investments over their more geographically remote holdings.

The influence of geography on the operation of and access to financial markets is also evident simply by examining the characteristics of different asset classes. For example, investors from all over the world have access to highly liquid global equity markets and rely on country by country and stock exchange specific disclosure requirements to inform their decision-making. On the other hand, the venture capital asset class is accessible only to a few institutional and high-net worth individuals, is highly concentrated by geographical clusters and it is characterized by a lack of public information on potential investments (Rin et al., 2011). Hence, it requires a very labour intensive investment process which relies on extensive networks of entrepreneurs (Bachher et al., 2014). The geography inherent across different asset classes is highly relevant for the growth of both green technologies and fintech, as companies evolve from a seed funding stage dependent on capital from founders, business angels and venture capitalists, to an established company which secures its funding from global public financial markets or investment banking syndicates.

Unlike organizations across many other industries, financial organizations have few tangible assets and depend mostly on people, governance procedures and information systems which support human capital and decision-making processes (Clark and Monk, 2017). The asset allocation decision-making process of investment organizations such as

pension funds or asset managers has been largely influenced by modern portfolio theory (Markowitz, 1952), which facilitated the replacement the assessment of the risk profile of individual securities with the assessment of the risk profile of asset classes and portfolios of securities in asset allocation decisions (Clark and Monk, 2017). For example, Rudd (1981) reaches the "inescapable conclusion" that excluding assets from a portfolio based on social (or environmental) criteria creates by default investment risk. This statement was based on the widely held belief that any deviation from fully diversified portfolios across industries and geographies (based on the country of incorporation of companies) would lead to inferior returns (Rudd, 1981).

This is in contrast with much of the academic literature showing how concentrated investment portfolios with good performance on environmental, social and governance risk factors either performed on par with conventionally diversified investment portfolios or in some cases even outperformed them (Clark et al., 2014; Derwall et al., 2005; Friede et al., 2015; Hoepner et al., 2016; Ibikunle and Steffen, 2017). Hoepner (2010) shows that Rudd's (1981) conclusion does not hold, given that portfolio diversification depends on three components: the number of assets in a portfolio, the correlation between assets and the standard deviation of assets. Hoepner (2010) argues that while indeed the decrease of the number of assets negatively influences portfolio diversification, scholars neglect the fact that the standard deviation of specific assets is still an important factor in portfolio diversification. In the context of the uneven impacts of climate change, traditional geographical risk diversification by the companies' country of incorporation is unlikely to be fit for purpose (Mercer, 2015). Hence, the concept of diversification can apply to the notion of material and geographically contextual environmental risks in addition to traditional financial risk factors used in asset pricing (Cojoianu et al., 2015).

Financial geographers have also been preoccupied with the development of and dynamics between international financial centres (IFCs), which feature sparsely in the

economics literature despite the constant attention that both policymakers and the financial sector devote to IFCs (Cassis, 2010; Cassis and Wójcik, 2018; Wójcik et al., 2018b). Financial centres are highly relevant to the development of environmental financial markets as well as financial technologies, since new types of financial markets rely on the financial infrastructure of IFCs (Knox-Hayes, 2009). This reliance is not only built upon capital and technological resources, but also on the knowledge and social ties of actors within a financial centre (Clark, 2018; Knox-Hayes, 2009).

Finally, a review of the contribution of financial geographers would not be complete without mentioning the state – finance nexus theme (Clark, 2000; Martin, 1999), which was explored from diverse perspectives including: the role of pension policies on the development of domestic financial markets (Clark, 2000; Scharfstein, 2018), the forms and functions of prominent institutions like sovereign wealth funds (Clark et al., 2013; Monk, 2011) and central banks (Reinhart and Rogoff, 2013) and indeed the topic of financial regulation. Capital allocation shifts towards both green technologies and fintech are already impacted by the state through a broad spectrum of interventions (Arner et al., 2016; Hepburn, 2010).

The thesis approaches these themes throughout the four substantive chapters, with a particular focus on the tensions between the scope of decision making of financial intermediaries, their operation at different geographical scales (Chapter 3 ,5 and 6) and the geographical scale of their clients (Chapters 3,4 and 5).

2.3 The geography of innovation

In addition to observing and seeking to understand why economic activity is spatially concentrated (Krugman, 1993), economic geographers and industrial theorists have shown that spatial concentration is a feature which is even more pronounced for innovative activity (Audretsch and Feldman, 2004; Feldman, 1994). This has sparked the

development of a rich literature trying to explain the origin, development and dynamics of innovation clusters, which also found a large audience across policymakers looking to replicate the Silicon Valley phenomena (Braunerhjelm and Feldman, 2006; Sunley and Martin, 2003).

The empirical investigation of innovation has historically taken two research avenues. The first focuses on innovation outputs and its determinants, chief among them being geographically mediated knowledge spillovers (Audretsch, 1995; Feldman, 2000). The second one investigates the impacts of innovation on economic growth or productivity. This section will focus on the first angle, as the thesis is concerned with green innovation and fintech innovation and the role of financial intermediaries.

The importance of new economically-relevant knowledge has been highlighted by several early studies as a key ingredient to innovation (Audretsch and Feldman, 2004; Cohen and Klepper, 1992). What was also widely accepted is that new knowledge created spills, but it was unclear in early research whether knowledge spillovers are mediated by geography (Audretsch and Feldman, 2004). Hence, localisation theories emerged to explain the decay of knowledge spillover across geography (Audretsch and Lehmann, 2005).

One argument in favour of geographically-mediated knowledge spillovers comes from the inherent difference between codified and tacit knowledge (Clark, 2018; Lawson and Lorenz, 1999). The knowledge spectrum can be conceptualised as ranging from completely tacit, such as the experience of people or uncodified organisational routines, to completely explicit, codified knowledge that can be immediately accessible to other individuals or organisations other than those who originated it (Leonard and Sensiper, 1998). Scholars argue that while the costs of transmitting codified knowledge across the world have become invariant with the Internet and telecommunication-related innovations, "[…] the marginal cost of transmitting knowledge, especially tacit

knowledge, is lowest with frequent social interaction, observation and communication" (Audretsch and Feldman, 2004, p. 2719). In this sense, the local and informal ways in which tacit knowledge is transmitted is one of the factors which suggest that geographic proximity mediates knowledge spillovers and ultimately, innovation (Audretsch, 1995; Audretsch and Feldman, 2004; Feldman, 1994; Glaeser et al., 1992). The clustering of innovative activity has also been tied to factors such as co-location benefits resulting from the proximity to R&D centres and universities (Audretsch and Lehmann, 2005; Feldman, 1994), proximity to organisations with complementary assets and sources of knowledge (Teece, 1986) and as importantly, the benefits of locating in places that have infrastructure which supports the innovative process.

The opportunity to innovate based on new knowledge isn't available only to incumbent organisations, but also to new entrants (Acs et al., 2009; Audretsch, 1995). The knowledge spillover theory of entrepreneurship (KSTE) suggests that the main sources of entrepreneurship opportunities are new ideas and knowledge that are created by incumbent firms, universities, research organisations or individual inventors but left uncommercialized (Acs et al., 2009; Agarwal et al., 2010; Audretsch and Keilbach, 2007a). Acs et al. (2009) argue that this is possible due to the divergence in the valuation of new knowledge between new entrants and knowledge creators, as well as the higher ability of new entrants to bear the costs of uncertainty associated with uncommercialised knowledge. New entrants can come in contact with new knowledge through several channels including: supplier-customer relationships, formal and informal professional associations and the movement of highly skilled human capital (Feldman and Kelley, 2006). Knowledge spillover isn't automatic however. It also requires that new entrants possess prior contextual knowledge that allows them to absorb newly created knowledge and to employ it in a commercial context (Qian, 2018; Qian and Acs, 2013).

How are these insights applicable to financial intermediaries in the context of environmental investing and financial technologies? There are multiple implications. First, the geography of technology clusters is highly likely to influence where both environmental technologies and financial technologies emerge. I analyze this in both Chapter 4 and 6, where I unveil the relevance of knowledge spillovers in the emergence of both cleantech and fintech. Second, the location of these emerging industries and that of the incumbent fossil fuels and financial sectors are likely to impact the investment strategies and innovation activities of financial intermediaries. In the context of Chapter 3, I show how the location of financial intermediaries in relation to fossil fuel companies affects the funding of fossil fuels. In Chapter 4, the thesis shows that while regional finance availability for environmental entrepreneurs is important, regional new knowledge creation and environmental policies can be equally salient in determining cleantech start-up emergence. In the context of financial technologies, I investigate the relative importance of knowledge created in financial sector incumbents as compared to knowledge created in the IT sector in fintech innovation emergence (Chapter 6). Last but not least, I investigate how environmental credit risks assessments can be incorporated in the decision making of lenders and how this is dependent on knowledge about environmental risks and the ability to operationalise them through information systems (Chapter 5). In other words, the concepts of knowledge and innovation are at the heart of the thesis aims.

2.4 Environmental investing

To understand the present form, function and legitimacy of environmental markets and environmentally conscious investors, I will refer first to the evolution of socially responsible investing (SRI). SRI has its roots amongst religiously motivated investors who have historically avoided investing in what are called “sin stocks”, or that shares of

companies involved in the tobacco, firearms, gambling or alcohol industries (Richardson, 2009; Schueth, 2003). The influence of these early religious groups has been instrumental in fostering what is now known as the sustainable investment industry, through the creation of the first ethical investment data provider, EIRIS, and the first socially responsible investment fund in 1928.

The view that environmental, social and governance risks can be financially material for businesses, and consequently for their investors, has emerged post-World War II with the increasing power of trade unions and the rise of consumer and civil rights movements (Biehl et al., 2012; Hoepner, 2013). Other notable movements that shaped the development of SRI include the South African divestment campaign as a boycott against the apartheid government (Hunt et al., 2017) or the divestment in the 1960s and 1970s by the anti-Vietnam War movement (Richardson, 2009).

In the past three decades, investors grew more and more concerned with the question of whether, beyond ethical screens, it is possible that environmental, social and governance criteria can help reduce portfolio risk and/or enhance the returns of their investment portfolios (Kempf and Osthoff, 2007; Hoepner and Wilson, 2010; Friede, Busch and Bassen, 2015). This meant that, besides investing according to one's values as many religious investors still do, a wide range of institutional investors are actively analysing ESG datasets pertaining to issues that are likely to be material to the bottom line of their investee companies or projects. Hence, there is a wide range of investment strategies that investors currently employ in what both academics and industry practitioners refer to as sustainable investments (Clark et al., 2014; Friede et al., 2015). These include: i) positive screening or best in class investing – where investors only allocate funds to the top-performing companies in terms of their ESG profile; ii) ESG integration - where the ESG risk or opportunity profiles of companies are considered along financial data points in the investment process; iii) active ownership and

engagement is a strategy usually employed by equity investors post investing in a particular company through proxy voting, shareholder resolutions or management dialogue; iv) partial or full divestment usually occurs when investors decide that the ESG performance of a company or sector is unlikely to change and may experience the financial consequences in the medium to long term (e.g. fossil fuel divestment due to the prospect of asset stranding) (Ayling and Gunningham, 2017; Carbon Tracker, 2011; Le Billon and Kristoffersen, 2019). The implications of this strategy are explored in more depth in the next section.

Given the urgency to both mitigate and adapt to climate change and the need to shift capital from fossil fuel industries to the emerging low carbon economy (David, 2017; Mackenzie and Ascui, 2009; Mercer, 2015), environmental investing has emerged both as a standalone industry practice as well as a subject of academic inquiry under the sustainable finance umbrella. Environmental investing comprises the four investment strategies described above, with an explicit focus on environmental issues. In addition, environmental investing is also concerned with the financing of low carbon technologies across asset classes as well as with the financing of companies or projects that seek to reduce the environmental harm embedded in modern products and services.

The now substantial literature on environmental finance has mainly focused on establishing the link between environmental performance and corporate financial performance across the equities and bonds (Friede et al., 2015), but less so across industries that rely heavily on syndicated or unsecured loans (Cojoianu and Ascui, 2018). The reason for this is that in private financial markets, which are less liquid than public markets for equities and bonds, there are limited disclosure requirements, particularly with respect to the disclosure of environmental performance. Hence, the proliferation of environmental risk datasets, particularly related to greenhouse gas emissions and water issues (Cojoianu et al., 2015) in a public financial market context, led to a paucity of

research on asset classes such as bank lending or private equity. The thesis seeks to fill this literature gap by unveiling insights on the links between the environment and syndicated bank lending in the oil and gas sector (Chapter 3), entrepreneurship (Chapter 4) and small-scale loans to agriculture (Chapter 5). Below, I review the literature on the links between environmental factors and financial performance across asset classes.

The meta-study of Friede et al. (2015) unveils the fact that the majority of studies find a positive relationship between corporate environmental performance and corporate financial performance. The meta-study of Hang et al. (2019) confirms these findings and provide further insights on reverse causality between the two constructs. The authors find that, in the short-term (i.e. one year), a firm's positive financial performance can lead to an increase in the environmental performance, but these effects are not observed on longer time frames. On the other hand, the study shows that the environmental performance of a company has no effect on its short-term financial performance, but rather, it has a positive effect on the long-term financial performance (Hang et al., 2019).

In equity markets, Derwall *et al.* (2005) show that eco-efficient companies significantly outperform environmental laggards over the 1995 – 2003. This investment signal tends to be material across industries where energy consumption is highly important for a company's bottom line, such as real estate (Eichholtz et al., 2010). Research on green mutual funds shows mixed results depending on the geography and time frame in which the financial performance analysis is carried out. For example, Chang (2012) finds that US green funds underperform over the 2008 – 2011 period. In contrast, Ibikunle and Steffen (2017) analyze the performance of European green, fossil fuel and conventional mutual funds over the 1991 – 2014 period and find that green mutual funds perform on par with their peers. After 2012, the study also observes significant outperformance of green funds over fossil fuel funds. Last but not least,

Muñoz et al. (2014) show that equity green investments performed on par with other sustainable investment funds in a study across both US and European funds.

Interest in green investment in the fixed income asset class has grown only recently with the surge in green bond issuances by corporates, municipalities and sovereign governments around the world (Climate Bonds Initiative, 2018; Mackenzie and Ascui, 2009). However, academic work on this topic is still in its infancy. Chiesa and Barua (2019) investigate the factors related to the size of corporate green bond issuance and find that green bond issue size is positively related with the credit rating, collateral availability, and the issuer's sector. Baker et al. (2018) study closely US municipal green bonds and unveil the fact that they are issued at a premium compared to plain-vanilla bonds. The article also finds that green municipal bonds tend to have a more concentrated ownership structure, particularly when green bonds are externally certified as green. Research on private financial market instruments such as loans and how environmental sustainability factors are linked with either bank practices or with the performance of loan instruments (Zeidan et al., 2015) tends to be much scarcer, mostly due to data availability issues for both environmental and financial datasets (Berger and Udell, 1998). The literature so far has documented that firms with better sustainability performance ratings experience a lower cost of debt, in particular those companies that operate in countries with better sustainability credentials (Bauer and Hann, 2010; Clark et al., 2014; Hoepner et al., 2016; Nandy and Lodh, 2012). Most papers also focus on large-scale corporate loans and bond finance, rather than smaller loans to privately held companies and SMEs. There is, to the best of our knowledge, no peer-reviewed research demonstrating a clear link between environmental performance at this smaller scale, and the availability, terms or cost of bank loans. The thesis addresses this literature gap in Chapter 5, by providing insights into how environmental risk factors can be operationalised in the credit risk management processes of banks that provide smaller-

scale loans to farming enterprises. The choice of the agricultural sector is motivated by the impacts and dependencies on natural capital that the sector has, which makes environmental risk factors highly material.

2.5 The fossil fuel divestment campaign

Partial or full fossil fuel divestment is one of the strategies that investors can use in their quest to impact climate justice. The reasons behind the decision to divest from fossil fuels can be based on values, financial rationales or a combination of both (Beer, 2016). The fossil fuel divestment campaign had modest beginnings, with students at a small number of US universities asking their administrations to sell stocks in fossil fuel companies since 2010 (Ansar et al., 2013). It soon became the fastest growing divestment movement in history, with divestment pledges reaching $8.05 trillion at the end of 2018[5] from c. 1,027 institutions ranging from pension funds, sovereign wealth funds to universities, cities or NGOs.

The fossil fuel divestment movement is as a nonstate governance intervention operating through symbolic political action (Ayling and Gunningham, 2017). Gunningham (2017) distinguishes between two types of goals of the divestment movement: to stigmatize the fossil fuel extraction industry and to pressure institutional investors into divesting their stocks from fossil fuel extraction. Richardson (2017) suggests that there are several pressure points that the divestment movement exerts upon financial services actors, particularly investors. These include an emphasis on: the legal responsibility of investors to act in the best interest of their clients, on the social license of investors to avoid complicity in fossil fuel industries and the financial benefits of investing in environmental solutions.

[5] https://gofossilfree.org/divestment/commitments/

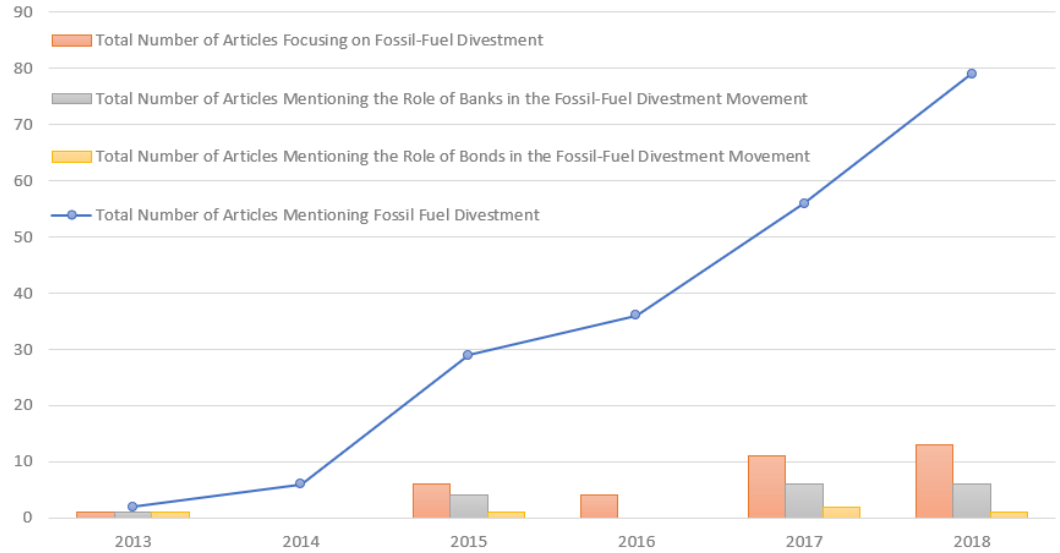
The emergence of anti-fossil fuel norms has incentivised both innovation in financial product development, such as fossil fuel free indices (Trinks et al., 2018), and the formation of investor coalitions looking to leverage their collective influence over the fossil fuel industry (PRI, 2016). The origins of the movement on university campuses meant influenced the choice of asset classes that activists focused on. As university endowment funds do not necessarily hold large amounts of fossil fuel related financial assets nor invested in new issuances of fossil fuel financial assets (Ansar et al., 2013; Beer, 2016) both activists and much of the academic literature focused on asset owners who invest in fossil fuels through shares traded on secondary markets, despite the fact that the sector obtains the majority of its funding through investment bank syndicated loans and bonds (EY, 2014). To confirm this, I conduct a literature review of 208 studies that mention the fossil fuel divestment movement. I shortlist these studies by using the following keywords on the Scopus and Web of Knowledge search functions: fossil-fuel divestment, fossil fuel divestment, oil divestment, coal divestment, gas divestment, tar sands divestment, fossil-fuel disinvestment , fossil fuel disinvestment, oil disinvestment ,coal disinvestment ,gas disinvestment ,tar sands disinvestment ,fossil-fuel divesture ,fossil fuel divesture ,oil divesture ,coal divesture ,gas divesture ,tar sands divesture.

Articles for the year 2018 are those indexed by Scopus and Web of Knowledge by the 19th of November 2018. While I did not restrict the paper search to any particular timeframe, it emerges that academic studies have picked up the fossil fuel divestment theme after the widely publicised article of Bill McKibben in 2012 in which the activist brought the attention to the divestment movement (McKibben, 2012). Out of the 208 peer-reviewed studies mentioning the movement over the 2013 -2018 period, 35 studies focus specifically on different aspects and implications of the fossil fuel divestment movement. I conduct further searches and review the 35 studies hence obtained in order

to unveil how many acknowledge the role of banks, bank loans or bonds in the divestment context.

Figure 2.1: Number of articles related to the fossil fuel divestment campaign on Scopus and Web of Knowledge.

As **Figure 2.1** illustrates, only half of the studies mention banks as a key investor in the debate and only 5 studies mention bonds as an asset class through which investors can influence fossil fuel fundraising. In addition, none of these studies focus on either bank loans or bonds, nor do they provide any insights into the link between the divestment movement and the cost of capital or fundraising ability of fossil fuel



companies. The studies of Trinks et al. (2018) and Hunt and Weber (2018) provide limited evidence on the financial performance of fossil fuel free equity portfolios in the US and Canada respectively.

The thesis addresses the literature gap related to the divestment movement by explicitly focusing on bank financing of oil and gas companies in primary markets in Chapter 3. The study unveils the factors related to oil and gas syndicated loan and equity and bond issuances at the country level, including the role of country level fossil fuel divestments and environmental policies.

2.6 Environmental policy

The renowned Stern Review has framed climate change as "the greatest market failure the world has ever seen" (Stern, 2006, p. viii). The report has also recognised that the climate market failure interacts with other market imperfections, and that environmental policy across the world should primarily seek to provide an explicit price for emitting GHGs (Hepburn, 2006) and to support the innovation in and deployment of low carbon technologies (Stern, 2007). Lord Stern advocates for a more active involvement of governments to ensure the delivery of the low carbon transition, which contrasts with the faith in market-based solutions for the allocation and coordination of capital which prevailed over the last half-century, particularly in Anglo-American economies with private pension systems (Clark, 2000; Knight, 2010; Scharfstein, 2018).

Government intervention towards correcting environment-related market failures is not a black or white issue, but rather, a matter of different shades of green. Indeed, Hepburn (2010) shows that there is a broad spectrum between the fully "free market" model in which the government has no involvement and firms voluntarily acquire information on externalities and voluntarily internalise those externalities and the other extreme of "nationalised delivery", where the government delivers environmental protection and management services through its central departments. This middle ground includes government interventions related to information provision regarding environmental externalities; the deployment of price, quantity or hybrid policy instruments which provide price signals for the internalisation of environmental externalities (Hepburn, 2006), or even interventions through state-owned enterprises (Hepburn, 2010, 2006; Monk, 2011; Oireachtas, 2018).

While environmental economic theory provides useful frameworks and insights on the effective design of environmental policies, it is rare that environmental economic theory is observed in practice, mainly because environmental policy instrument design

depends largely on political-economy considerations rather than economic theory (Carroll et al., 2018; Hepburn, 2006; Zietsma et al., 2018). Regardless, the literature's focus with highlighting the impacts of environmental policy on competitiveness and innovation, as well as how policies translated into real environmental outcomes provides many useful insights which guide the focus of the thesis, particularly in Chapters 3 and 4.

The interest on the link between environmental policy and innovation was sparked by the declaration of Prof. Michael Porter almost three decades ago, that environmental innovation does not hamper innovation, but rather likely enhances it (Ambec et al., 2013; Porter, 1991). Studies looking to empirically test the Porter hypothesis (PH), have largely focused on the US manufacturing industries, with more recent studies expanding the geographic and sectoral coverage (Ambec et al., 2013; Dechezleprêtre and Sato, 2017). The early studies of Jaffe and Palmer (1997) and Brunnermeier and Cohen (2003) show that more stringent regulation results in higher environment related R&D expenditure and innovation outputs (proxied by patent applications). More specifically, some studies show for example that higher energy as well as road fuel prices have also been shown to encourage environmental innovation (Aghion et al., 2016; Popp, 2002).

The literature exploring the effectiveness of market vs. non-market policies in inducing innovation broadly confirms that market policy instruments (such as emission taxes or emissions trading schemes) are more effective than performance standards or specific technology mandates (Calel and Dechezleprêtre, 2016; Dechezleprêtre and Sato, 2017; Fabrizi et al., 2018). The evidence against this is slightly outdated, with the study of Popp (2003) on the introduction of the Clean Air Act in 1990 showing that innovation in flue gas desulfurization units decreased with the introduction of sulfur dioxide permit trading.

Generally, scholars proposing that markets provide better outcomes than state dictated policy, rely on the underlying model that prices generated in the context of dynamic markets allow firms and individuals to act more efficiently in the context of a

complex adaptive economic system (Schumpeter, 1942; Hepburn, 2010; Lo, 2012). In this respect, it is surprising that there are relatively few studies looking at the links between environmental regulation and environmental entrepreneurship, given the widely celebrated role of entrepreneurs as both agents of creative destruction (Schumpeter, 1942) and key actors driving economic growth (Acs et al., 2016). Studying this link has been historically difficult due to the unavailability of relative policy stringency measures across geographies but also due to the opacity of private equity and venture capital data, which makes the entrepreneurship phenomena challenging to analyse. The study of York and Lenox (2014) in the US finds that a higher count of state incentive policies is a positive and significant predictor of entry of diversifying incumbents into the green building sector but had no effect on entries of new firms. Hörisch et al., (2017) provides a wider coverage by focusing on OECD countries and illustrates that green entrepreneurship opportunities are negatively impacted by high environmental market taxes. Using these insights, the thesis seeks to contribute to the literature by analysing the impact of environmental policy stringency on entrepreneurship over 293 regions and 24 OECD countries (Chapter 4).

More recently, we have witnessed new ways in which government can intervene in financial markets with the purpose of nudging capital towards low carbon solutions and away from emission intensive activities. These include: the issuance of sovereign green bonds, the divestment of sovereign wealth funds from fossil fuels, the set-up of both financial and nonfinancial institutions to promote green investment both domestically and internationally, the promotion of green central banking policies to aid asset allocation by financial institutions (Bank of England, 2018; Chiesa and Barua, 2019; Hargadon and Kenney, 2012; Liesen et al., 2015; Oireachtas, 2018), and the mandating of climate related disclosures among others. In this light, the thesis contributes to the environmental policy literature by showing how both traditional policy instruments and divestment

pledges from different tiers of government influence fundraising amounts in the oil and gas sector across 33 countries (Chapter 3).

2.7 Financial technologies

Information and communications technologies have been at the core of the development of the financial industry that we know today (Arner et al., 2016). Whether it is the introduction of the telegraph, the first successful transatlantic cable connection in 1866, or indeed, the introduction of the Automatic Teller Machine (ATM), technological innovations have often had significant spillovers in and impacts on the financial services industry (Arner et al., 2016). Hence, how can we explain and conceptualize the emergent financial technology or fintech ecosystem after the global financial crisis, which is comprised of startups, technology companies and mainstream financial institutions such as banks, asset managers or insurance companies alike?

Wójcik and Cojoianu (2018b) argued that the financial crisis created the suitable conditions for the emergence of fintech, given that much of the reputation of financial firms was damaged (Sapienza and Zingales, 2012), while the technology sector has had a good reputation among both the investment world and the public, with little regulatory oversight. On the technological side, the advancements in data science, the increased computational power to process large datasets (often termed as “big data”) but as importantly, the wide penetration of smart phones, meant that the technology sector had the means and the distribution channel to reach the population of both developed and developing economies with new financial services innovations (Wójcik and Cojoianu, 2018a).

The types of financial products and services that would fall under the fintech umbrella are numerous, and there is currently no comprehensive taxonomy to analyse the sector given its relative recent emergence. In this respect, Chapter 6 seeks to provide a

taxonomy of the sector by triangulating the classifications used among both academic and industry reports. One useful definition of fintech which characterises the diverse ecosystem is that fintechs are "organisations combining innovative business models and technology to enable, enhance and disrupt FS [financial services]. This definition is not restricted to start-ups or new entrants, but includes scale-ups, maturing companies and even non-FS companies, such as telecommunication providers and e-retailers" (EY, 2016, p. 21).

The market size for financial technology solutions has recently reached significant proportions. Financial sector was incumbents alone have spent approximately US$500 billion on information technology in 2016 (IDC, 2018). Funding for fintech start-ups grew from just US$3.8 billion in 2013 to US$16.6 billion in 2017 (CBInsights, 2018). The most notable trend is the rise of Asia, from $200 million invested in fintech in 2012 to $8.5 billion in 2016, becoming the region with the largest recent investments in the sector. On a deal number basis, North America is leading with over 50% of investments, followed by Europe with c. 28% and Asia with 13% of deals (Autonomous Research and Pitchbook, 2017). This reflects that in Europe and North America numerous lower value deals are going into a diversified fintech ecosystem, whereas Asia is dominated by fewer by larger deals which have been targeted at lending platforms and payment infrastructure development (Accenture, 2016).

What we know about the fintech sector which emerged after the global financial crisis is very limited, with academic contributions coming mainly from the fields of entrepreneurship, innovation studies and management. The entrepreneurship and innovation literature has so far shown what some generic likely determinants for the emergence of fintech start-ups are. Haddad and Hornuf (2018) find that the availability of venture capital financing, the number of secure internet servers and mobile subscriptions are positively related with fintech entrepreneurship while the ease of access to loans

experienced by companies in a given country is negatively correlated with new fintech start-ups. Following a similar research design, Cumming and Schwienbacher (2018) investigate fintech venture capital funding patterns across 63 countries and find that after the financial crisis, investments in fintech start-ups are more likely to take place in countries with weaker regulatory enforcements and by venture capitalists that have less experience with prior VC boom and bust cycles. From an exit perspective, the authors find that these deals tend to be less successful when located in countries without a major financial centre. Patent applications in fintech seem to be profitable across the different types of fintech organisations, particularly if these innovations are blockchain related (Chen et al., 2018). The management and finance literature has focused on issues such as the impact of communication dynamics on peer-to-peer lending platforms (Xu and Chau, 2018), determinants of cryptocurrency pricing (Mai et al., 2018), the impact of the sustainability orientation of borrowers on crowdfunding campaign outcome (Calic and Mosakowski, 2016) or insights into the competition between emerging start-up products and sell-side investment content products of traditional financial services providers (Grennan and Michaely, 2018).

The literature has yet to clarify important questions with respect to whether financial technologies are more likely to emerge in technology clusters or financial centres, how this differs across start-ups, technology or financial services incumbents or how new data-related technologies could be incorporated in the decision-making processes of financial services incumbents. The thesis seeks to cover these questions in depth through Chapters 5 and 6, by investigating fintech innovation in both start-ups and incumbents across 226 regions and then exploring how the proliferation of environment related datasets and new data technologies could be used to enhance the credit rating decision making process of mainstream lenders.

3 The Economic Geography of Fossil Fuel Divestment, Environmental Policies and Oil and Gas Financing

3.1 Introduction

"*A social movement that only moves people is merely a revolt. A movement that changes both people and institutions is a revolution*." Martin Luther King, *Why We Can't Wait* (1964)

Despite the entry into force of the Paris Agreement in November 2016, global emissions have yet to peak and reached a high of 53.5 $GtCO_2e$ in 2017 (UN, 2018). So far, aggregate nationally determined contributions to GHG emission reductions are inadequate to ensure global warming stays below 2°C. One reason for this is that despite new investment in renewable energy reaching a historical high (BNEF, 2019), we have also reached historical highs in funding of fossil fuels (EY, 2014) and many countries have already committed to building fossil fuel infrastructure which would take the world past 2°C warming (Pfeiffer et al., 2018). It is therefore important to understand the factors that most influence the flows of capital into fossil fuels, at a global level.

A helpful framework to analyse this problem is through the lens of economic geography. Economic geographers have framed climate change as a problem of collective action which has inherent geographical challenges, given the need to coordinate across the political, economic, financial and social landscapes (Knight, 2010), and the unevenness of climate impacts across the globe (Yohe and Schlesinger, 2002). The stabilisation of global warming under any warming target requires the achievement of a net-zero emissions economy (Matthews and Caldeira, 2008). For this to be plausible, scholars have suggested that new financing of fossil fuel infrastructure needs to stop and up to 20% of existing infrastructure should be stranded (Pfeiffer et al., 2018). Economic geography can provide useful insights on the links between finance and fossil fuel infrastructure, as geographers have historically taken interest in both the physical

geography of the natural resources sector as well as how this is interwoven with global capital flows in the energy sector, and more broadly with the political economy of states and the geographic coverage of climate agreements (Bridge, 2008; Bridge et al., 2013; Le Billon and Kristoffersen, 2019).

In the past decade, the relationship between the financial industry and the fossil fuel industry has started to be shaped by the rise of anti-fossil fuel norms. Given the slow progress of government policies to adequately address climate change, and recognising the substantial influence the fossil fuel sector has on the policy-making process (Carroll et al., 2018; Le Billon and Kristoffersen, 2019; Zietsma et al., 2018), social activism has turned against the fossil fuel sector. The fossil fuel divestment movement started in 2010 with students at a small number of US universities asking their administrations to sell stocks in fossil fuel companies (Ansar et al., 2013), and gained global visibility in 2012, thanks to the *Rolling Stone* article of environmental activist Bill McKibben titled "Global Warming's Terrifying New Math" (McKibben, 2012), which advocated cutting the supply of financial capital to the fossil fuel industry (Green and Denniss, 2018; Le Billon and Kristoffersen, 2019). By 2013, it was already identified as the fastest growing divestment campaign in history (Ansar et al., 2013), with over US$8 trillion divested to date. The movement has been conceptualised by scholars as a nonstate governance intervention operating through symbolic political action and through the active management of anti-fossil fuel norms (Ayling and Gunningham, 2017; Green, 2018). In other words, the divestment movement has been focusing on investors in the fossil fuel sector without involving formal regulatory intervention, although the expectation has been that government action would follow social action (Gunningham, 2017b).

This paper seeks to answer several questions. First, how effective is the divestment movement at actually shifting investment away from fossil fuels? Are divestment

pledges by different types of institution equally effective? Have governments managed to achieve any net reduction in fossil fuel capital flows with environmental policies?

To answer these questions, we ground our research in the fields of economic and financial geography, and environmental economics. At a conceptual level, the financial geography literature proposes that capitalism can be studied through the decision-making, social practices and geographical scope of financial institutions (Clark, 2005; Martin, 2010). Financial geography also provides a framework for understanding the evolution of financial institutions as organisations, whether these are institutional investors, investment banks, stock exchanges or sovereign wealth funds, among others (Lee *et al.*, 2009; Clark, Dixon and Monk, 2013; Wójcik, Knight, *et al.*, 2018). We link these bodies of research with research in environmental economics which has a long tradition in studying the effectiveness of policy instruments in reducing environmental degradation at different geographical scales, as well as how these policies impact economic outcomes such as innovation outputs, profitability of companies and competitiveness of organisations, regions or countries (Ambec et al., 2013; Dechezleprêtre and Sato, 2017; Hepburn, 2006).

Using a global database of equity and bond issuance and syndicated loan transactions in 33 countries from 2000-2015, this paper analyses the relationships between country level oil and gas fundraising amounts, the cumulative assets pledged for fossil fuel divestment at the country level and the stringency of environmental policy instruments. We find that overall, an increase in fossil fuel divestment commitments at a country level is related to lower new total fundraising by the oil and gas sector. We also find that both domestic and foreign investment banks reduce their overall financing and underwriting of a country's oil and gas sector with the rise in divestment commitments particularly by local, regional or national governments or government-backed financial

entities. On the other hand, there is no statistically significant relationship between the dollar amount of financing and underwriting to foreign oil and gas companies by domestic investment banks and divestment commitments in the banks' home countries. Finally, we show that among the traditional environmental policy instruments, more stringent emissions trading schemes at the country level are related to a decrease in new fundraising levels of a country's oil and gas sector.

The paper is structured as follows: section 3.2 reviews the theoretical background and explains the rationale for our main hypotheses; section 3.3 details the data and empirical methodology; section 3.4 provides top level descriptive statistics followed by a synthesis of results and discussion in section 3.5.

3.2 Theoretical background and hypotheses

3.2.1 The fossil fuel divestment movement

Unlike the anti-Apartheid movement, which focused on destabilising a government regime in one particular country, the anti-fossil fuel movement is focused on convincing asset owners and institutional investors to divest from the fossil fuel sector globally (Hunt et al., 2017). The movement has attracted attention to climate issues through stigmatising fossil fuel companies, as well as by engaging in arguments about morality, economics and justice (Ansar et al., 2013; Gunningham, 2017a; Mangat et al., 2018). The economic and financial arguments are rooted in the stranded assets hypothesis, which asserts that fossil fuel related assets will likely face devaluations and write-downs as the world transitions to a low carbon economy. It has been calculated that society needs to keep more than 80% of fossil fuel reserves in the ground in order to limit climate warming to 2°C (Caldecott et al., 2016; Carbon Tracker, 2011).

The appeal of the movement on university campuses meant that a large amount of attention has been placed on the endowment funds of universities, as well as public sector

pension funds; neither of which tend to directly hold large amounts of fossil fuel related equity or debt (Ansar et al., 2013; Beer, 2016). As a result, most literature is focused on asset owners who invest in fossil fuels through shares or bonds traded on secondary markets. Secondary markets comprise shares or bonds that have already been issued by companies and are only traded among investors. While Ansar et al. (2013) and Richardson (2017) recognise that the financial services actors that are most likely to impact the fundraising for new fossil fuel infrastructure are investment banks, given their significant balance sheet exposure to the oil and gas sector (EY, 2014), the majority of studies rarely mention or focus on the impact of new debt issuance in the shape of syndicated bank loans or new fossil fuel bond issuance.

The emergence of global anti-fossil fuel norms has legitimised the launch of financial products related to fossil fuel divestment, including fossil fuel free indices, which are sold to institutional investors around the world (Ayling and Gunningham, 2017). Fossil fuel divestment pledges have reached $8.05 trillion from c. 1,027 institutions (as of January 2019)[6], but it is unclear what difference they have made. Evidence related to the performance of fossil fuel free portfolios is very limited and so far, restricted to the equity asset class. Trinks et al. (2018) conduct a robust financial performance analysis of US investment portfolios with and without fossil fuel companies over the period 1927 – 2016. They find that portfolios without fossil fuel companies do not underperform market benchmarks, mainly because fossil fuel companies provide relatively few diversification benefits. In the Canadian context, Hunt and Weber (2018) study different fossil fuel divestment strategies applied to the Canadian stock index TSX 260 over the period 2011 – 2015. The study found that divesting from coal, energy equipment and services and consumable fuels can result in a strategy that outperforms the

[6] https://gofossilfree.org/divestment/commitments/

Canadian market index, but other divestment strategies that extend to the entire energy and utilities sector tend to underperform. So far, no study analyses whether the divestment movement has been successful in either decreasing the amount of new capital raised by fossil fuel companies or whether their cost of debt has increased because of social activism. We aim to do the former, and hence test the following hypothesis:

H.1: The stock of assets under management pledged for fossil fuel divestment in a given country is negatively related to the amount of new capital raised by the oil and gas sector in that country.

The divestment movement has gained traction with a diverse range of organisations and institutions across the globe. These include both financial organisations (banks, insurance companies, venture capital firms, asset managers and pension funds) and non-financial organisations (NGOs, foundations, faith-based organisations, private companies and governmental institutions). This raises the questions of whether or not divestment pledges by different types of institution are equally effective, and whose divestment commitments influence oil and gas fundraising the most.

Social norms gain more legitimacy when governments act as "active norm managers" by seeking to encourage behaviours that are in line with certain expectations (Kinzig et al., 2013). Law-and-norm theorists have suggested that active "norm management" by governments can be an uncoercive and inexpensive way to deal with problems that have complex solutions, such as climate change (Ela, 2009). As far as phasing out fossil fuels is concerned, a decision by sovereign, regional or local governments to divest their own assets from fossil fuels (and thereby encourage other investors to do the same) would be an example of an active norm management approach. Hence, we hypothesise that:

H.2: The stock of assets under management pledged for fossil fuel divestment by sovereign, regional or local governments in a given country is negatively related to the amount of new capital raised by the oil and gas sector in that country.

3.2.2 The geography of oil and gas fundraising

The geography of oil and gas fundraising emerges from the intersection between the physical geography and political economy of the oil and gas sector (Bridge, 2014, 2008; Bridge et al., 2013; Le Billon and Kristoffersen, 2019) and the geography of finance (Clark and Wójcik, 2007; Clark, 2005; Lee et al., 2009; Leyshon, 1998).

The oil sector is a producer driven value chain in which the majority of operational control lies with the administrative headquarters of the transnational (or state owned) oil and gas company. Much of the extractives sector relies on their relationship with nation states, as fossil fuel reserves are sovereign assets, even if this sovereign right is temporarily revoked through contractual agreements with commercial domestic and foreign entities (Bridge, 2008; Le Billon and Kristoffersen, 2019). Le Billon and Kristoffersen (2019) also recognise the lobbying power of the fossil fuel industry (Zietsma et al., 2018) – including the lack of pressure on fossil-fuel producing governments from the international community, with respect to achieving the low carbon transition.

These dynamics are closely interlinked with the geography and dynamics of global finance, which has been the focus of enquiry for financial geographers (Clark, 2017, 2000; Wójcik, 2011b; Wójcik et al., 2018b) and financial intermediation theorists (Allen and Santomero, 1998; Arner et al., 2016; Scholtens and van Wensveen, 2000). Throughout history, this geography has been shaped by institutions and organisations which ultimately contributed to the achievement of four important functions of a financial system: the provision of a payment system; the matching of lenders with borrowers; the management of personal finances across individual lifetimes and inter-generationally; and the provision of risk management services to individuals and businesses (Davis et al., 2016; Kay, 2015). The matching of capital with those who seek

capital is a service that has fallen mostly in the remit of banks and has boomed after the 1980s with the introduction of 401(k) accounts in the US and the rising amounts of pension fund assets looking for suitable investments (Clark, 2000). The rise of the investment banking sector to global power has hence been fuelled by the growth of the securities industry, which investment banks heavily underwrite and market to institutional investors (Wójcik, 2012). Modern banks undertake a range of services and functions in-house (Clark and Monk, 2017), from securities underwriting to asset management and lending. For the purpose of this paper, we focus on their functions as lenders and underwriters of equity and debt securities.

Both syndicated lending and securities underwriting rely on the "relationship banking" business model, where the decisions to lend to or underwrite a company's equity or bond issuance are based not only on objective quantitative datapoints (e.g. profitability or liquidity), but also on soft information (Hoepner et al., 2016), which cannot be accurately represented by a numeric score and is therefore more subjective in nature (e.g. trustworthiness, competence, impact of social norms on license to operate and other factors) (Gropp and Guettler, 2018). Hoepner et al. (2016) show that soft information related to the environmental and social risk factors at a country level have a statistically and economically significant effect on direct financing of companies across sectors. More precisely, the higher the environmental and social risk in a country, the higher the cost of bank loans. Much of the recent literature on banking and sustainability shows that banks have started to incorporate many "soft indicators" related to the environmental and social sustainability of the companies they provide financial services to (Weber et al., 2015, 2008), but the sophistication of this incorporation is unequal across different types of indicators and asset classes, depending on the knowledge, IT systems, budgets of banks and the availability of suitable methodologies and information

to do so (Cojoianu et al., 2015; Cojoianu and Ascui, 2018). Another salient aspect is that after the financial crisis, a lot of attention has been directed not only at the stability and decision making of the banking sector, but also to its contribution towards sustainable economic activities (Hoepner and Wilson, 2010). This literature suggests that banks may have started to consider the reputational risks associated with financing or underwriting the oil and gas sector, and potentially decrease their overall exposure to the industry, particularly in countries where doing otherwise is highly stigmatised by the fossil fuel divestment movement. This may not be true, however, for oil and gas companies in the Middle East or in countries where oil and gas extraction is organised through state-owned companies, which tend to depend less on non-state financing, including Western investment funds (Le Billon and Kristoffersen, 2019). As the recent $12 billion bond issuance of Saudi Aramco shows, there is high appetite from investors and investment banks to finance the debt of state-owned fossil fuel companies (Bloomberg, 2019).

While the internal processes of many banks are important, the fundraising of many large companies does not rely only on the capabilities of individual banks, but rather on the strength of the syndicates that lead banks can convene towards financing or underwriting large deals such is the case in the oil and gas sector (Fight, 2004). International syndicates come in different configurations depending on the financing needs of the domestic sector of a country as well as capital availability and the expertise of domestic banks (Fight, 2004; Vekshin, 2013; Wójcik, 2011a; Wójcik et al., 2018c), but investment banking syndicates share many organisational routines, systems and processes across their international constituent banks (Knight and Wójcik, 2017). In this respect, we hypothesise that oil and gas fundraising and underwriting from domestic and foreign investment banks are both related in a similar way to fossil fuel divestment claims:

H.3: The stock of assets under management pledged for fossil fuel divestment in a given country is negatively related to the total amount raised by the oil and gas sector from both domestic and foreign investment banks.

The hypotheses above rely on the assumption that fossil fuel divestment commitments in a country mostly affects the fundraising of the domestic oil and gas sector. Is it also possible that banks headquartered in countries with divestment commitments export fewer financial services to foreign oil and gas companies? There is wide consensus that investment banks are specialised across sectors, hence we expect that those investment banks that finance the oil and gas sector in their home countries will be able to export this expertise abroad. Much of the divestment movement has focused on stigmatising oil and gas companies and sought to win over the investment community with economic, ethical and legal arguments rather than stigmatising investors themselves. Moreover, while climate change and the commitment to fight against it may have reached the global stage, the fossil fuel divestment movement has so far been an Anglo-American movement with splillovers across continental Europe. Indeed, many institutions choose different financial strategies for the low carbon transition, including direct engagement with oil companies or tilting their portfolios towards less carbon intensive industries, but not full divestment. Hence, we expect that:

H.4: The stock of assets under management pledged for fossil fuel divestment in the home country of a bank is not related to the bank's financing and underwriting of foreign oil and gas companies.

3.2.3 Environmental policy and oil and gas fundraising

In this section, we use insights from environmental economics to form our hypotheses regarding the potential impact of environmental policy stringency on the fundraising of the oil and gas sector. Hepburn (2006) argued that much of the economic theory employed for environmental policy design has yet to be tested given that its design and implementation are almost always driven by political factors rather than

economic theory rationales. While not focusing directly on the costs of capital or fundraising ability of regulated entities, environmental economists have been long preoccupied with the competitiveness of companies targeted by environmental regulation (Dechezleprêtre and Sato, 2017). Competitiveness has been measured through varied indicators including cost of production, profitability, employment or market share, but not cost of capital or capital fundraising ability.

The two parallel lines of enquiry into this topic are referred to as the pollution haven hypothesis and the Porter hypothesis (Ambec et al., 2013). The pollution haven hypothesis states that more stringent environmental policies will over time cause the shift of pollution or emission intensive production to low abatement cost regions, thereby creating pollution havens. On the other hand, the Porter hypothesis argues that a more stringent environmental policy regime can enhance competitiveness through the cost-cutting and innovation activities that companies undertake and which offset compliance costs (Ambec et al., 2013; Lanoie et al., 2011; Porter and Linde, 1995).

The pollution haven hypothesis has been tested by examining the links between environmental regulation and international trade, foreign direct investment (FDI) and location choices. The import of more energy and emission intensive goods has been largely found to be positively related with an increase in environmental policy stringency, although its effects tend to be very small and concentrated in a small set of industries (e.g. manufacturing, cement, iron, steel or aluminium) (Sato and Dechezleprêtre, 2015). Inward FDI has been found to be negatively related to the increase of environmental policy stringency in the US chemicals and primary metals sector (Xing and Kolstad, 2002), but the economic significance of this effect is very small compared to US FDI outflows. Overall, Dechezleprêtre and Sato (2017) state that the discrepancy between the high attention given to the issue in policy circles and the

very limited evidence supporting it, may be due to either the overstatement by companies as a lobbying tool against more stringent regulations, or due to governments setting environmental policies that avoid competitive distortions.

The evidence for the Porter hypothesis, or at least for one version of it, has been to date more convincing. Scholars find the strongest evidence in showing that environmental regulation does not hamper, but rather enhance innovation (Ambec et al., 2013; Calel and Dechezleprêtre, 2016; Jaffe and Palmer, 1997). This however, usually comes with a short term cost of complying with environmental regulations which ultimately is not offset by policy induced environmental innovation (Lanoie et al., 2011). In some contexts, this is due to the fact that increased investment in emissions abatement technologies may be carried out to the detriment of other innovation related investment (e.g. electric car patents crowding out combustion engine related patents, Aghion et al., 2016).

In this context, we propose to study the effect of different environmental policies on primary market investment flows in the oil and gas sector. Since many environmental policies are aimed at phasing out fossil fuels (David, 2017), we expect bank financing and underwriting of fossil fuel equity and debt to be lower in countries with more stringent environmental policies. This can be interpreted as an indication that environmental policy is related to decreased competitiveness, which we proxy by the ability of the oil and gas sector to fundraise. Finally, if the pollution haven hypothesis holds, we may observe that banks decide to export financial services to foreign oil and gas companies if the domestic sector experiences increased policy induced operational costs. Hence, we hypothesise that:

H.5: More stringent environmental policies are negatively related to new fundraising levels in the domestic oil and gas sector.

H.6: More stringent environmental policies are positively related with the exports of financial services of domestic banks to foreign oil and gas companies.

3.3 Data and methodology

3.3.1 Dependent variable

Country oil and gas fundraising

The dependent variable is the total amount of capital raised ($ million) by all oil and gas companies (public and private) in a given country and year. The financial instruments through which funds are raised in the oil and gas sector are new equity and bond issuances as well as syndicated loans from investment banks. Project finance is less used by the oil and gas sector compared to the power and utilities sector, mainly due to the unpredictability of oil and gas projects compared to other infrastructure projects. Hence, much of the financial risk is taken by the companies themselves (EY, 2014).

We use the Dealogic database to construct a country variable of total fundraising by oil and gas companies (across equity, bond issuance and syndicated loans) across the world. Dealogic is a global database of investment bank transactions which includes details on investment bank advisors and their clients for 673,102 fundraising deals across equity and debt issuance and syndicated loans between 2000 and 2015. We use the industry classification provided by Dealogic, which is based on the North American Industry Classification (NAICS), to identify oil and gas companies. The sample of public and private oil and gas companies come from sub-industries such as: oil and gas extraction, distribution, oil and gas equipment manufacturing, oil and gas well drilling, oil and gas pipeline construction and operation and oil and gas refinery and marketing. Hence, we identify 19,057 fundraising events across the three financial instruments for the oil and gas sector (5,718 equity issuances; 3,754 bond issuances and 9,585 syndicated loans). We use the country of incorporation of the company to aggregate the total fundraising by country, as well as the country of incorporation of the investment banks to

determine whether the funding (in the case of loans) or underwriting (in the case of equity or bond issuance) was arranged by domestic banks or foreign banks. In addition, we quantify the total financing that a country's domestic investment banks finance provides to foreign oil and gas companies.

We are able to collect key independent variables and control variables over the 1999 – 2015 period for 33 countries: Australia, Austria, Belgium, Brazil, Canada, China, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Italy, Japan, Mexico, Netherlands, Norway, Poland, Portugal, Russia, Slovak Republic, South Africa, South Korea, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

3.3.2 Independent variables

Country fossil fuel divestment commitments

Data to quantify the cumulative divestment commitments by financial organisations (banks, insurance companies, venture capital firms, asset managers and pension funds) and non-financial ones (NGOs, foundations, faith-based organisations, private companies and governmental institutions) was obtained from the Divest Invest initiative.[7] Divest Invest collects all the public fossil fuel divestment commitments as well as the assets pledged to be divested by these organisations and institutions, since the first public divestment commitment of the 350.org NGO in 2008, who spearheaded the divestment initiative in the US. The key independent variable is hence aggregated as the cumulative assets pledged for divestment (in $ million) by country and by the type of organisation.

Country OECD environmental policy stringency

[7] https://www.divestinvest.org/about/

To analyse the effect of traditional environmental policy instruments on both total fundraising of oil and gas companies and the domestic vs. foreign investment banking activity in the sector, we use the environmental policy indices constructed by the OECD which cover our 33 countries between 1999 – 2012 (Botta and Koźluk, 2014). The index has not been updated by the OECD for 2013 and 2014 and hence, given the slow changing nature of policy, we assume the same index values for the years 2013 and 2014 as in the year 2012.

The environmental policy stringency (EPS) composite indices are obtained from custom weighting the values of more granular groups of indicators. First, the stringency of individual policy instruments (e.g. feed-in-tariff for wind and feed-in-tariff for solar) are assigned a value between 0 (not existing) and 6 (most stringent), which are then aggregated in an equal-weighted manner to an aggregate policy instrument value (e.g. FIT wind + FIT solar = FIT overall index; the full methodology can be found in the paper of Botta and Koźluk, 2014). The scoring procedure is designed to benchmark the stringency of an individual policy instrument across countries and time.

The term environmental policy stringency is defined as both: "a higher, explicit or implicit, cost of polluting or environmentally harmful behaviour […] for instruments like taxes"(Botta and Koźluk, 2014, pp. 14) as well as incentives for the development of environmental technologies and processes such as feed-in-tariffs or R&D subsidies. **Table 3.1** provides an account of the different types of policy instrument indices used in the analysis.

Table 3.1: OECD Environmental Policy Stringency (EPS) index construction.

EPS Composite	**EPS Policy Instrument**	**EPS Individual Policy**
EPS Aggregate	Taxes (0.16)	CO_2, NO_x, SO_x,
	Trading Schemes (0.16)	CO_2, Renewable Energy Certificates, Energy Efficiency Certificates.
	Feed-in-Tariffs (FITs) (0.16)	Solar, Wind
	Standards (0.25)	Emission Limit Values: NO_x, SO_x and PM_x
	R&D Subsidies (0.25)	Government R&D

	Expenditure on Renewable Energy

Note: EPS policy instrument weights used for aggregation at country overall policy stringency are specified in parentheses. Adapted from Botta and Koźluk (2014).In parentheses we included the weights that the OECD uses to aggregate the policy instrument level indices to obtain the EPS composite index.

3.3.3 Control variables

We outline the list of control variables we use in the full models, alongside the data sources and description for each (see **Table 3.2**).

Table 3.2: Dependent, independent and control variables description and data sources.

Variable Name	Variable Description	Data source
OG.Fundraising	Total oil and gas sector fundraising by country (equity issuances, bond issuances and syndicated loans to oil and gas companies)	Dealogic
Divest.Total	Total cumulative assets of institutions and organisations pledging to divest from fossil fuels by country from year of divestment pledge announcement.	Divest Invest Initiative
Divest.Financial	Total cumulative assets of financial organisations pledging to divest from fossil fuels from year of announcement (banks, insurance companies, venture capital firms, asset managers and pension funds)	Divest Invest Initiative
Divest.Non.Financial	Total cumulative assets of non-financial organisations pledging to divest from fossil fuels from year of announcement (NGOs, foundations, faith-based organisations, private companies, governmental institutions)	Divest Invest Initiative
Divest.Non.Financial.Ex.Gov	Total cumulative assets of non-financial organisations, excluding governmental organisations, pledging to divest from fossil fuels from year of announcement (NGOs, foundations, faith-based organisations, private companies)	Divest Invest Initiative
Divest.Gov	Total cumulative assets of governmental organisations pledging to divest from fossil fuels from year of announcement (sovereign wealth funds and government financial institutions, city councils and regional governments)	Divest Invest Initiative
Environmental Policy Stringency (EPS)	Country level annual indices of environmental policy stringency.	OECD iLibrary.
GDP.Capita	GDP per capita	OECD iLibrary.
Env.Patents	Fractional green patent counts per year.	OECD REGPAT, OECD iLibrary.
RE.TE	Country renewable energy as percentage of primary energy supply.	OECD Statistics.
OG.Revenue	Revenues of listed oil and gas companies by country.	Sustainability Accounting Standards Board SICS Classification and Bloomberg.
Oil.Prod	Oi production – ktoe annually by country.	OECD Statistics.
Gas.Prod	Gas production- bcf annually by country.	International Energy Agency (IEA)

3.3.4 Model specification

The analysis is carried out at the country level, with data organised in a balanced panel for 33 countries over the period 2000 – 2015. We employ a two-way log normal OLS regression model which accounts for country and year fixed effects and clusters model standard errors at both the country level and over time (Kölbel et al., 2017; Petersen, 2008). Given the high correlation between GDP per capita and the composite

EPS index, as well as the R&D subsidies and Standards indices, we orthogonalize the latter variables with respect to GDP per capita, to avoid multicollinearity issues. In addition, gas production at the country level is highly correlated with oil production, hence we orthogonalize this measure with respect to oil production.

All regressors are lagged by one year. We do not lose any observations since we code all independent variables from 1999 onwards. The full models we estimate can be expressed by the following equation, where μ_t and d_t are the time and country effects and $\varepsilon_{i,t}$ is the stochastic error.

$$\ln(OG.Fundraising_{i,t}) = \beta_1 * ln(Divest.Total_{i,t-1}) + \beta_2 * \ln(EPS_{i,t-1}) +$$
$$\beta_3 * ln(GDP.Capita_{i,t-1}) + + \beta_4 * \ln(Env.Patents_{i,t-1}) +$$
$$\beta_5 * ln(OG.Revenue_{i,t-1}) + \beta_6 * ln(Oil.Prod_{i,t-1}) +$$
$$\beta_7 * ln(Gas.Prod_{i,t-1}) + \beta_8 * ln(RE.TE_{i,t-1}) + \mu_t + d_t + \varepsilon_{i,t}$$

3.4 Descriptive statistics

Low cost of debt that has enabled the rise of green bonds and the funding of green infrastructure, has also benefited the funding of fossil fuel companies (see **Figure 3.1**). Oil and gas sector fundraising has surged from $234 billion in 2000 to c. $700 billion in 2015, with an average year-on-year growth rate of 9.17% in fundraising volume across all financial instruments (bank loans, bonds and equity issuance). Bank loans were by far the preferred means of fundraising for the oil and gas sector (c. 64% of total fundraising over the 2000 – 2015 period), followed by bonds (26%) and equities (10%). The preference towards syndicated loans is often related to the advantage of speed of transaction and lower information disclosure requirements over other financial instruments such as bonds (Fight, 2004).

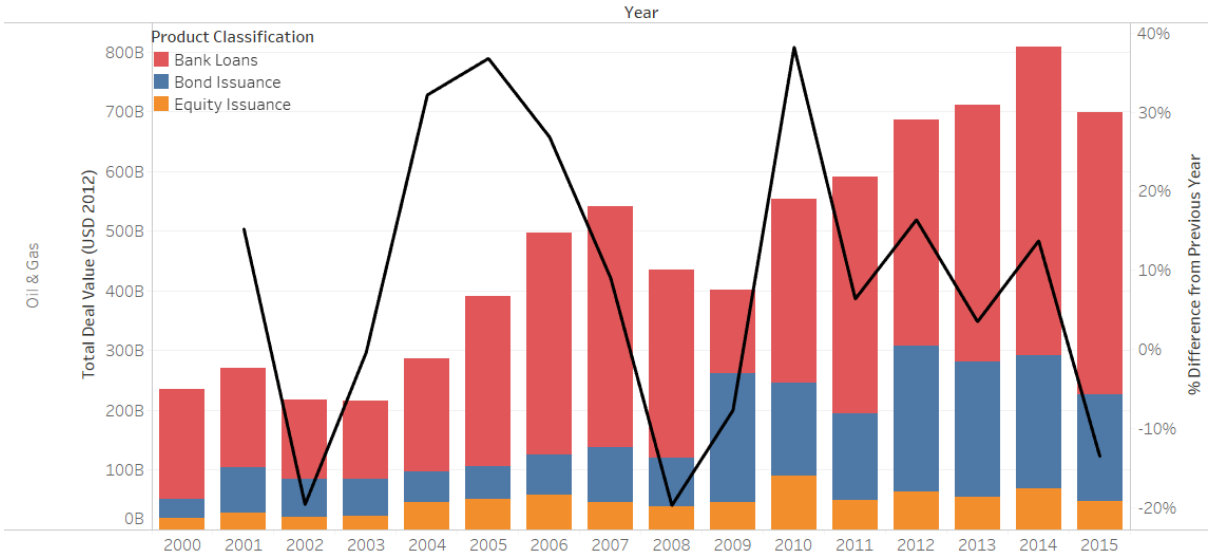


Figure 3.1: Global oil and gas bank loan financing, equity and bond issuance or underwriting amount. Data from Dealogic.

Given the large amounts fundraised by oil and gas companies, individual banks cannot take the full size of the loans on their balance sheet, and hence, they often form syndicates to provide companies with the required capital. Syndicated loan participation by domestic banks (located in the same country with the oil and gas company seeking capital) tends to be matched by foreign investment banks in terms of the amount provided to oil and gas companies in a given country (**Figure 3.2**). Bond issuance on the other hand, is more likely to be underwritten by foreign investment banks, which suggests that oil companies seek foreign financial market participants primarily to buy into their bonds. Equity issuance historically was underwritten more by domestic banks but in recent years foreign banks have, in aggregate, matched the amounts underwritten by domestic banks, and even surpassed them in some years.

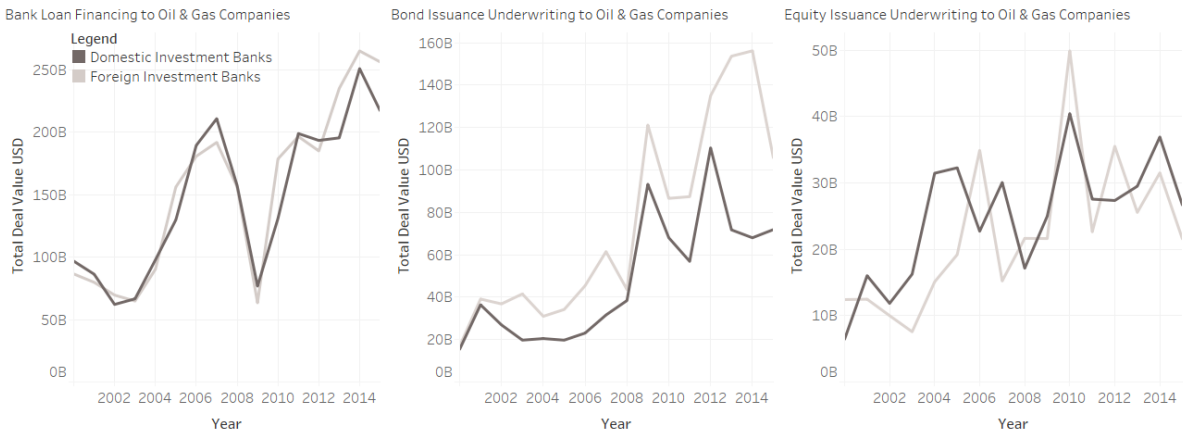


Figure 3.2: Global oil and gas financing from domestic banks vs. foreign bank, given the home country of oil and gas companies. Data from Dealogic.

We can, however, observe significant heterogeneity at the country level in terms of domestic vs. foreign bank financing and underwriting of the domestic oil and gas companies. While the loans to oil and gas companies in countries such as the US, are equally financed by domestic and foreign investment banks, Russia and Norway depend more on foreign investment banks, while Japan relies mostly on its own banks for capital. Bond underwriting in China is overwhelmingly supported by domestic banks, while for companies in the UK, France and the Netherlands, it is foreign banks that mostly underwrite their debt (**Figure 3.3**). Overall, the US attracts over 43% of the global capital in the oil and gas sector, with US based companies fundraising over $3.2 trillion between 2000 and 2015. The US is followed by Canada ($958 bn – 12.7% of overall oil and gas capital), Russia ($336 bn – 4.6%), UK ($264 bn – 3.5%), Netherlands ($244 bn – 3.2%) and Japan ($236 bn – 3.1%) (see **Appendix A.3.1**).

The fossil fuel divestment campaign has reached significant proportions across organisations from NGOs and government organisations to financial institutions. The total pledges for divestment reached over $8.05 trillion from c. 1,027 institutions between 2008 and 2018. Norway ranks highest in divestment commitments ($1.176 trillion), given the recent recommendation of Norge Bank towards the Norwegian Ministry of

Finance to have the Global Pension Fund ($1 trillion assets under management) divest from fossil fuels (NBIM, 2017). Switzerland follows closely with $902 billion pledged for fossil fuel divestment, mainly driven by the re-insurance giants Zurich Insurance and Swiss Re. While the US is 4th in total divestment commitments with c. $836 billion (after France - $846 billion), the US and the UK lead in total assets committed for divestment by NGOs, academic institutions and faith organisations with $178 million and $43 million respectively (see **Appendix A.3.2**).

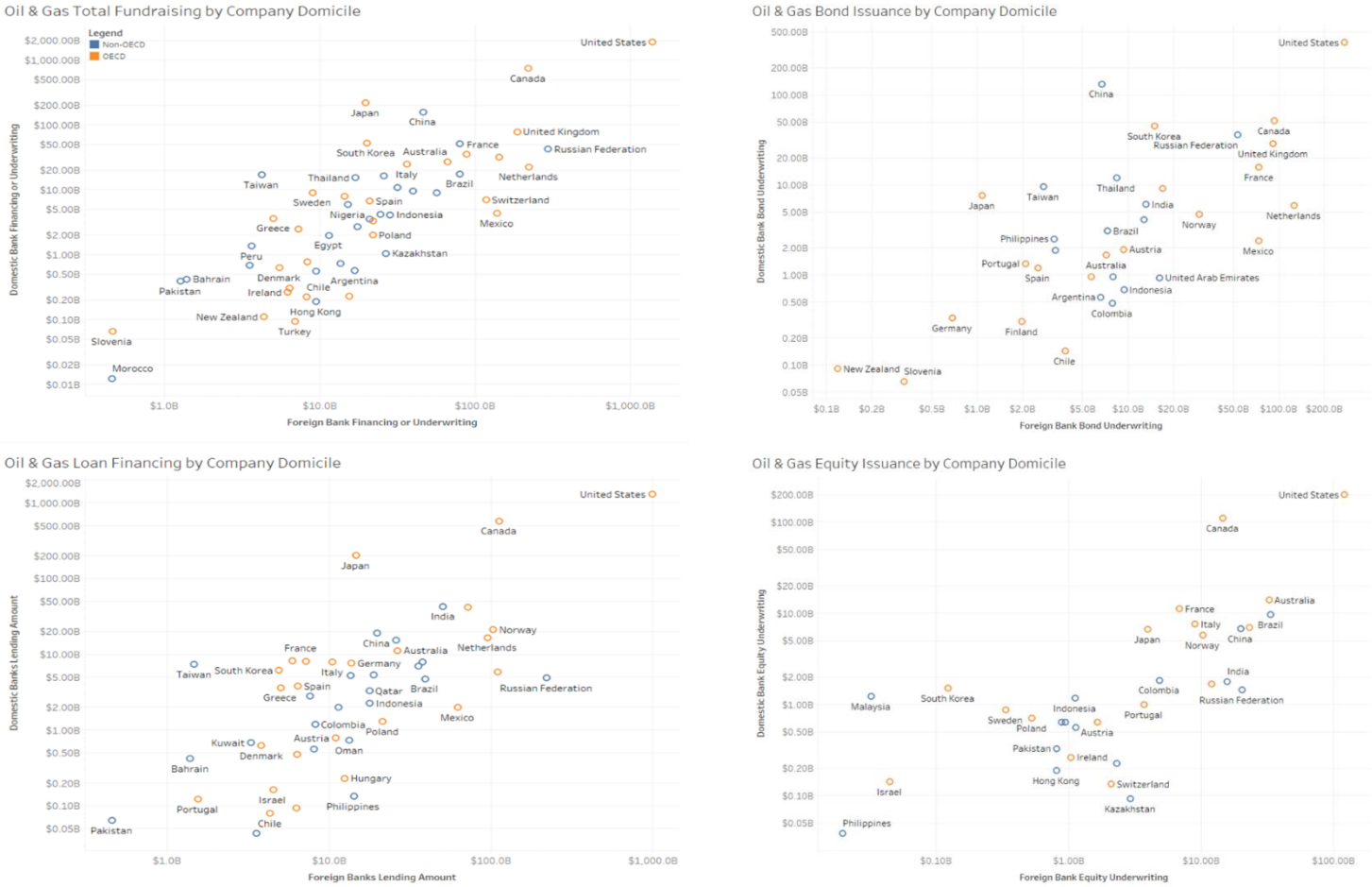


Figure 3.3: Domestic vs. foreign bank financing and underwriting of oil and gas across countries and asset classes. Data from Dealogic.

3.5 Synthesis of results

Total oil and gas fundraising

First, we analyse the effect of the fossil fuel divestment movement as well as that of environmental policy stringency on the total oil and gas fundraising amounts by country between 2000 and 2015 (**Table 3.3**). All models are specified as log-log regressions; hence the results should be read as: A 1% increase in the independent variable leads to a β % increase in the dependent variable. Model 1.a shows the effect of our control variables, which remain robust throughout all other models. The revenues of the listed oil and gas sector are a significant factor related to total fundraising in the sector ($\beta = 0.25$, $p < 0.001$). In other words, a 1% increase in revenues of the oil and gas sector at the country level, is related to an increase of 0.25% in fundraising the following year. The gas production variable is orthogonalized with respect to oil production, given that these two variables are highly correlated. The models show that gas production which is uncorrelated with oil production negatively impacts oil and gas fundraising ($\beta = 0.68$, $p < 0.05$). On the other hand, GDP per capita, environmental innovation (measured by environmental patents) and renewable energy supply percentage do not have a significant effect on fundraising.

In models 1.c – g, we test the relationship between the cumulative assets under management committed for fossil fuel divestment by country on total oil and gas fundraising, while also including the effects of traditional environmental policy instruments. We find that a 1% increase in the assets under management committed to divestment is significantly and negatively related to a 0.11% reduction in new fundraising by oil and gas companies headquartered in that country (models 1.f and 1.g, $\beta = -0.11$, $p < 0.01$). For a country such as the UK, whose oil and gas sector fundraised on average $16.5 billion every year between 2000 and 2015, the economic significance of

the relationship is sizeable. An increase of $1 billion in the cumulative assets-under-management pledged for divestment in the UK in 2015 is related to a decrease of c. $350 million in total fundraising by the UK oil and gas sector.[8]

We further investigate which types of institutions committing to fossil fuel divestment have a bigger impact on total oil and gas fundraising (models 3.a – d). We find that divestment pledges from non-financial institutions (NGOs, foundations, faith-based organisations, private companies, governmental institutions) are the strongest drivers of reductions in oil and gas fundraising ($\beta = -0.16$, $p < 0.05$), while divestment pledges from financial organisations are insignificant. Model 3.c illustrates the effect of divestment pledges by governmental organisations, which shows a negative and significant relationship ($\beta = -0.07$, $p < 0.1$). Using the same assumption as before, a $1 billion increase in divestment commitments from governmental organisations is related to a $266 million decrease in oil and gas fundraising at the country level.

As far as the environmental policy variables are concerned, we find a significant and negative effect of emissions trading schemes on oil and gas fundraising ($\beta = -0.49$, $p < 0.05$, model 2.g), while all other indices of environmental policy stringency are not significant. These initial findings are in line with our hypothesis that there is a significant and negative relationship between the rise of anti-fossil fuel norms and the fundraising ability of the oil and gas sector (H.1). In addition, the price signal emerging from emissions trading schemes seems to be the most influential in curbing fossil fuel finance, in line with our expectations that environmental policy stringency is a material risk to the oil and gas sector (H.5). The interpretation of the relative effect of different policy instruments must be interpreted with caution. The indices are useful for comparing their

[8] All other variables being held constant. In this calculation we use the real values for the UK for 2015. For different countries and baseline variables specifications, economic significance is different.

relative effects across countries but are not built to reflect the relative stringency across different types of policy instruments (Botta and Koźluk, 2014; e.g. a score of 4.5 of environmental tax stringency is not comparable with a score of 4.5 in the trading schemes stringency category). While tax is not significant in this research set-up, it may be that it is offset by fossil fuel subsidies which governments around the world still have in place.

Table 3.3: Total oil and gas fundraising (2000 – 2015).

Dependent Variable: Total O&G Fundraising	**Controls**	**EPS**	**Divest EPS**	**Taxes & Divest**	**Trading Schemes & Divest**	**FIT & Divest**	**Standards & Divest**	**R&D Subsidies & Divest**	**Divest & All Policy (1)**	**Divest & All Policy (2)**	**Non Financial**	**Non Financial Ex. Gov**	**Gov**	**Financial**
Models	**1.a**	**1.b**	**1.c**	**2.a**	**2.b**	**2.c**	**2.d**	**2.e**	**2.f**	**2.g**	**3.a**	**3.b**	**3.c**	**3.d**
GDP.Capita	-0.74	-0.94	-1.07	-1.02	-0.90	-0.91	-0.99	-0.74	-0.73	-0.73	-0.74	-0.74	-0.63	-0.57
	(1.12)	(1.21)	(1.19)	(1.13)	(1.16)	(1.13)	(1.18)	(1.22)	(0.88)	(1.34)	(1.33)	(1.33)	(1.33)	(1.34)
Env.Patents	0.17	0.15	0.14	0.15	0.15	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.16	0.17
	(0.38)	(0.38)	(0.38)	(0.38)	(0.39)	(0.38)	(0.38)	(0.38)	(0.27)	(0.39)	(0.39)	(0.39)	(0.39)	(0.39)
OG.Revenue	0.25***	0.25***	0.25***	0.25***	0.25***	0.25***	0.25***	0.25***	0.25**	0.25***	0.25***	0.25***	0.25***	0.25***
	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.07)	(0.09)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)
Oil.Prod	0.04	0.07	0.06	0.04	0.02	0.06	0.05	0.02	-0.00	-0.00	-0.00	-0.00	-0.01	-0.02
	(0.12)	(0.11)	(0.10)	(0.11)	(0.11)	(0.11)	(0.11)	(0.13)	(0.13)	(0.16)	(0.15)	(0.16)	(0.16)	(0.16)
Gas.Prod	-0.68*	-0.67*	-0.67*	-0.67*	-0.70*	-0.67*	-0.69*	-0.74*	-0.75**	-0.75*	-0.77*	-0.76*	-0.76*	-0.77*
	(0.30)	(0.30)	(0.29)	(0.29)	(0.29)	(0.30)	(0.29)	(0.32)	(0.28)	(0.36)	(0.33)	(0.34)	(0.35)	(0.36)
RE.TE	-0.54	-0.48	-0.53	-0.60	-0.46	-0.63	-0.57	-0.73	-0.64	-0.64	-0.63	-0.63	-0.59	-0.56
	(0.64)	(0.62)	(0.62)	(0.64)	(0.63)	(0.64)	(0.63)	(0.66)	(0.39)	(0.66)	(0.65)	(0.65)	(0.66)	(0.66)
EPS		-0.73	-0.61											
		(0.64)	(0.65)											
Taxes				0.31					0.15	0.15	0.09	0.10	0.14	0.18
				(0.44)					(0.39)	(0.36)	(0.35)	(0.35)	(0.36)	(0.36)
Trading.Schemes					-0.36				-0.49*	-0.49*	-0.49*	-0.48*	-0.54**	-0.58**
					(0.22)				(0.24)	(0.21)	(0.20)	(0.21)	(0.18)	(0.20)
FIT						-0.17			-0.22	-0.22	-0.21	-0.21	-0.23	-0.24
						(0.21)			(0.16)	(0.20)	(0.21)	(0.21)	(0.20)	(0.21)
Standards							-0.16		0.04	0.04	0.07	0.06	0.03	0.00
							(0.45)		(0.44)	(0.41)	(0.41)	(0.41)	(0.41)	(0.41)
RDsubsidies								0.67	0.73^	0.73	0.72	0.71	0.72	0.72
								(0.67)	(0.38)	(0.64)	(0.65)	(0.65)	(0.64)	(0.63)
Divest.Total			-0.12*	-0.13**	-0.11*	-0.13**	-0.13**	-0.14**	-0.11**	-0.11^				
			(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)	(0.03)	(0.06)				
Divest.Non.Financial											-0.16*			
											(0.08)			
Divest.Non.Financial.Ex.Gov												-0.18*		
												(0.08)		
Divest.Gov													-0.07^	
													(0.04)	
Divest.Financial														0.08
														(0.07)
Num. obs.	528	528	528	528	528	528	528	528	528	528	528	528	528	528
Adj. R^2 (full model)	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Country Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2-Way Standard Error Clustering	YES	YES	YES	YES	YES	YES	YES	YES	Year Only	YES	YES	YES	YES	YES

***p < 0.001, **p < 0.01, *p < 0.05, ^p < 0.1 – Robust clustered standard errors in parentheses.

Domestically intermediated oil and gas fundraising

Model 4.a (**Table 3.4**) shows the control variables related to the country level oil and gas fundraising intermediated by domestic banks. We find that a 1% increase in the percentage of renewable energy supply penetration is related to a 1.17% decrease in funding to domestic oil and gas companies by domestic investment banks.

While the total amount of committed assets for divestment by all types of institutions is not related to domestic bank financing and underwriting of the domestic oil and gas sector, we find that cumulative divestment commitments from governments have a negative and significant impact on domestic bank funding and underwriting ($\beta = -0.04$, $p < 0.05$, model 5.c). In other words, a $1 billion increase in cumulative divestment commitments in the UK from its 2015 base is related to a $103 million decrease in oil and gas fundraising and underwriting by UK domestic banks. We find no significant relationship with divestment commitments of other types of institutions.

We do, however, observe a persistent effect of environmental policy stringency indices on domestically intermediated oil and gas fundraising, both for the composite indicator ($\beta = -2.55$, $p < 0.001$, see models 4.b and 4.c) and at the individual policy instrument level (models 4.d and 5.a-d). Domestic bank financing of the oil and gas sector is negatively and significantly related to a country's stringency of both trading schemes ($\beta = -0.82$, $p < 0.01$) and feed-in-tariffs ($\beta = -0.32$, $p < 0.1$, model 4.d).

In line with our hypothesis (H.2), we find that the signal coming from divestment commitments by governments still holds when the statistical test looks more granularly at oil and gas financing from domestic vs. foreign investment banks. We do not find support for H.3, that the total amount of divestment pledges across all organisation types affects domestically intermediated oil and gas fundraising.

Table 3.4: Total oil and gas fundraising from domestic banks (2000 – 2015).

Dependent Variable: **Total O&G Fundraising from Domestic Banks**	**Controls**	**EPS**	**Divest EPS**	**Divest & All Policy**	**Non Financial**	**Non-Financial ex. Gov**	**Gov**	**Financial**
Model	**4.a**	**4.b**	**4.c**	**4.d**	**5.a**	**5.b**	**5.c**	**5.d**
GDP.Capita	-0.13	-0.83	-1.01	-0.57	-0.55	-0.57	-0.43	-0.43
	(0.81)	(0.98)	(0.92)	(1.18)	(1.18)	(1.18)	(1.23)	(1.23)
Env.Patents	0.28	0.23	0.20	0.22	0.23	0.22	0.24	0.24
	(0.32)	(0.30)	(0.30)	(0.30)	(0.30)	(0.30)	(0.30)	(0.30)
OG.Revenue	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.04
	(0.05)	(0.05)	(0.05)	(0.07)	(0.06)	(0.06)	(0.07)	(0.07)
Oil.Prod	0.06	0.14	0.14	0.05	0.04	0.05	0.04	0.05
	(0.14)	(0.11)	(0.11)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)
Gas.Prod	-0.21	-0.15	-0.16	-0.25	-0.27	-0.26	-0.26	-0.24
	(0.17)	(0.17)	(0.16)	(0.19)	(0.19)	(0.19)	(0.19)	(0.20)
RE.TE	-1.17*	-0.97*	-1.04**	-0.93*	-0.91*	-0.91*	-0.86*	-0.86*
	(0.48)	(0.38)	(0.38)	(0.36)	(0.37)	(0.37)	(0.36)	(0.36)
EPS		-2.55***	-2.39**					
		(0.73)	(0.77)					
Taxes				-0.39	-0.44	-0.43	-0.37	-0.35
				(0.70)	(0.71)	(0.71)	(0.68)	(0.67)
Trading.Schemes				-0.82**	-0.84**	-0.83**	-0.90***	-0.90***
				(0.27)	(0.27)	(0.28)	(0.26)	(0.26)
FIT				-0.32^	-0.32^	-0.31^	-0.34*	-0.34*
				(0.17)	(0.17)	(0.17)	(0.17)	(0.17)
Standards				-0.65	-0.63	-0.63	-0.68	-0.69
				(0.52)	(0.54)	(0.54)	(0.51)	(0.51)
RDsubsidies				-0.14	-0.15	-0.16	-0.16	-0.16
				(0.74)	(0.75)	(0.75)	(0.74)	(0.74)
Divest.Total			-0.17^	-0.15				
			(0.09)	(0.10)				
Divest.Non.Financial					-0.17			
					(0.13)			
Divest.Non.Financial.Ex.Gov						-0.20		
						(0.15)		
Divest.Gov							-0.04*	
							(0.02)	
Divest.Financial								-0.02
								(0.03)
Num. obs.	528	528	528	528	528	528	528	528
Adj. R^2 (full model)	0.78	0.79	0.79	0.79	0.79	0.79	0.79	0.79
Country Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES
2-Way Standard Error Clustering	YES	YES	YES	YES	YES	YES	YES	YES

***p < 0.001, **p < 0.01, *p < 0.05, ^p < 0.1– Robust clustered standard errors in parentheses.

Export of fundraising services to the foreign oil and gas sector

In this section we investigate whether the home country characteristics related to the oil and gas sector (including environmental policy and divestment commitments) are related to the amount of finance and underwriting that domestic banks export to foreign oil and gas companies (see **Table 3.5**). We find no evidence that the fossil fuel divestment campaign in the home country of banks has any influence on the total amount of financing and underwriting that these banks conduct outside the country (models 6.a – d and 7.a – d). Model 6.d provides the full results across both control and independent variables. This confirms H.4, which suggests that given that fossil fuel divestment stigma is targeted at companies rather than their investors, the export of financial services by banks is unlikely to be affected by the fossil fuel divestment commitments in the banks home country, unless banks specifically choose to deny services to fossil fuel companies.

The main drivers of financing and underwriting of the foreign oil and gas sector by domestic banks are: the revenue of the listed oil and gas sector ($\beta = 0.13$, $p < 0.05$), the annual volume of oil production ($\beta = 0.46$, $p < 0.05$), the variation in the annual volume of gas production which is uncorrelated with gas production ($\beta = 0.60$, $p < 0.05$) and the percentage of renewable energy in total energy supply of the home country of the investment bank ($\beta = -1.20$, $p < 0.05$). This suggests that the more developed the domestic oil and gas sector is, the more investment banks export financial services to oil and gas companies outside their home country. On the other hand, the greater the renewable energy penetration and the more stringent the feed-in-tariffs policies are in the home country of investment banks, the less banks export financial services to foreign oil and gas companies ($\beta = -0.62$, $p < 0.01$). Hence, we do not find any support for H.6, or the pollution haven hypothesis, which implied that banks would finance foreign oil and

gas companies if the domestic oil and gas sector faces more stringent environmental regulation.

Import of fundraising services for the domestic oil and gas sector

Here we outline the relationship between the domestic country characteristics and the total amount the oil and gas sector fundraises from foreign investment banks (**Table 3.6**). We find that only the divestment commitments of governmental organisations are a significant and negative driver of domestic oil and gas financing and underwriting by foreign banks ($\beta = -0.09$, $p < 0.05$, model 9.c). The stringency of a home country's trading scheme(s) is also negatively and significantly related to new financing by foreign banks ($\beta = -0.48$, $p < 0.05$). As far as the control variables are concerned, only the revenues of the listed oil and gas sector ($\beta = 0.29$, $p < 0.01$) and the volume of gas production uncorrelated with oil production ($\beta = -0.82$, $p < 0.05$) are significantly related with the amount fundraised by domestic oil and gas companies from foreign banks.

Table 3.5: Total foreign oil and gas financing and underwriting by domestic banks (2000 – 2015).

Dependent Variable: Total O&G Amount Funded by Domestic Banks Abroad	Controls	EPS	Divest EPS	Divest & All Policy	Non Financial	Non-Financial ex. Gov	Gov	Financial
Model	**6.a**	**6.b**	**6.c**	**6.d**	**7.a**	**7.b**	**7.c**	**7.d**
GDP.Capita	0.28	-0.17	-0.13	0.35	0.35	0.35	0.33	0.30
	(1.38)	(1.20)	(1.20)	(1.12)	(1.11)	(1.11)	(1.10)	(1.13)
Env.Patents	0.02	-0.01	-0.01	-0.02	-0.03	-0.02	-0.03	-0.03
	(0.29)	(0.25)	(0.25)	(0.25)	(0.25)	(0.25)	(0.25)	(0.25)
OG.Revenue	0.13*	0.13*	0.14*	0.13*	0.13*	0.13*	0.13*	0.13*
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Oil.Prod	0.38*	0.43*	0.43*	0.46*	0.46*	0.46*	0.46*	0.47*
	(0.18)	(0.20)	(0.20)	(0.21)	(0.21)	(0.21)	(0.21)	(0.21)
Gas.Prod	0.51*	0.55*	0.55*	0.60*	0.60*	0.60*	0.61*	0.61*
	(0.25)	(0.25)	(0.25)	(0.27)	(0.27)	(0.27)	(0.27)	(0.27)
RE.TE	-1.17*	-1.03^	-1.02^	-1.20*	-1.20*	-1.20*	-1.21*	-1.22*
	(0.52)	(0.54)	(0.55)	(0.57)	(0.57)	(0.57)	(0.56)	(0.57)
EPS		-1.64^	-1.68^					
		(0.95)	(0.95)					
Divest.Total			0.04	0.03				
			(0.06)	(0.07)				
Taxes				-0.47	-0.46	-0.46	-0.46	-0.48
				(0.62)	(0.63)	(0.63)	(0.63)	(0.63)
Trading.Schemes				0.03	0.04	0.03	0.04	0.06
				(0.34)	(0.33)	(0.33)	(0.33)	(0.35)
FIT				-0.62**	-0.62**	-0.62**	-0.62**	-0.62**
				(0.23)	(0.23)	(0.23)	(0.23)	(0.23)
Standards				-0.04	-0.04	-0.04	-0.04	-0.03
				(0.44)	(0.44)	(0.44)	(0.44)	(0.44)
RDsubsidies				-0.47	-0.47	-0.47	-0.47	-0.47
				(0.40)	(0.40)	(0.40)	(0.40)	(0.40)
Divest.Non.Financial					0.03			
					(0.08)			
Divest.Non.Financial.Ex.Gov						0.04		
						(0.08)		
Divest.Gov							0.04	
							(0.11)	
Divest.Financial								-0.03
								(0.05)
Num. obs.	528	528	528	528	528	528	528	528
Adj. R^2 (full model)	0.86	0.87	0.87	0.87	0.87	0.87	0.87	0.87
Country Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES
2-Way Standard Error Clustering	YES	YES	YES	YES	YES	YES	YES	YES

***p < 0.001, **p < 0.01, *p < 0.05, ^p < 0.1 – Robust clustered standard errors in parentheses.

Table 3.6: Total domestic oil and gas financing and underwriting of oil and gas companies by foreign banks (2000 – 2015).

Total O&G Fundraising from Foreign Banks	Controls	EPS	Divest EPS	Divest & All Policy	Non Financial	Non-Financial ex. Gov	Gov	Financial
Model	**8.a**	**8.b**	**8.c**	**8.d**	**9.a**	**9.b**	**9.c**	**9.d**
GDP.Capita	-0.97	-1.01	-1.12	-0.85	-0.87	-0.87	-0.78	-0.71
	(1.20)	(1.30)	(1.30)	(1.49)	(1.49)	(1.49)	(1.46)	(1.46)
Env.Patents	0.13	0.12	0.11	0.11	0.11	0.11	0.12	0.14
	(0.37)	(0.37)	(0.37)	(0.37)	(0.37)	(0.37)	(0.37)	(0.37)
OG.Revenue	0.29***	0.29***	0.29***	0.29**	0.29**	0.29**	0.29**	0.29**
	(0.08)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)
Oil.Prod	0.03	0.04	0.04	-0.03	-0.03	-0.03	-0.04	-0.05
	(0.10)	(0.10)	(0.09)	(0.14)	(0.14)	(0.14)	(0.14)	(0.14)
Gas.Prod	-0.70*	-0.70*	-0.70*	-0.80*	-0.82*	-0.81*	-0.82*	-0.83*
	(0.33)	(0.33)	(0.32)	(0.37)	(0.35)	(0.35)	(0.36)	(0.37)
RE.TE	-0.14	-0.13	-0.17	-0.26	-0.26	-0.26	-0.23	-0.19
	(0.68)	(0.66)	(0.66)	(0.67)	(0.67)	(0.67)	(0.67)	(0.68)
EPS		-0.15	-0.06					
		(0.71)	(0.71)					
Divest.Total			-0.10**	-0.08				
			(0.04)	(0.07)				
Taxes				0.14	0.09	0.11	0.12	0.17
				(0.40)	(0.39)	(0.38)	(0.40)	(0.40)
Trading.Schemes				-0.45^	-0.44^	-0.44	-0.48*	-0.53*
				(0.27)	(0.27)	(0.27)	(0.24)	(0.26)
FIT				-0.09	-0.08	-0.09	-0.10	-0.11
				(0.21)	(0.21)	(0.21)	(0.21)	(0.21)
Standards				0.06	0.09	0.08	0.06	0.03
				(0.53)	(0.53)	(0.53)	(0.54)	(0.54)
RDsubsidies				0.96	0.96	0.95	0.96	0.97
				(0.76)	(0.77)	(0.77)	(0.76)	(0.76)
Divest.Non.Financial					-0.14			
					(0.10)			
Divest.Non.Financial.Ex.Gov						-0.14		
						(0.11)		
Divest.Gov							-0.09*	
							(0.04)	
Divest.Financial								0.09
								(0.07)
Num. obs.	528	528	528	528	528	528	528	528
Adj. R^2 (full model)	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Country Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES
2-Way Standard Error Clustering	YES	YES	YES	YES	YES	YES	YES	YES

***p < 0.001, **p < 0.01, *p < 0.05, ^p < 0.1 – Robust clustered standard errors in parentheses.

3.6 Conclusions

This paper finds that the total assets pledged for divestment in a given country is negatively associated with capital flows to domestic oil and gas companies, particularly when divestment is led by governments. The study also shows that emissions trading schemes and renewables feed-in tariffs have been most effective in reducing oil and gas sector capital inflows. Feed-in-tariffs have been shown to be a significant driver of investment in and growth of the renewable electricity sector (Criscuolo and Menon, 2015; Georgallis et al., 2018; Georgallis and Durand, 2017), however, renewable electricity does not compete with the oil and gas sector. The mechanism at play could be that banks adjust their funding exposure from oil and gas to renewable opportunities through project finance or direct lending to mature green companies given the growth of renewables and not because FITs create greater risk for oil and gas companies. Testing this hypothesis would require investment banking data for both asset finance and company lending (BNEF, 2019). While this is encouraging, the fact that the oil and gas sector has been able to fundraise increasing amounts almost every year is sobering. For global warming to stabilise, society needs to achieve a net-zero economy (Matthews and Caldeira, 2008). This is unlikely to be achieved while new fossil fuel infrastructure is financed by investment banks and bond investors alike.

Our findings have wide ranging implications. For economic geographers and environmental economists interested in the impact of social norms on economic and environmental outcomes, the study shows that both place and the geographical boundaries of social norms are highly relevant in understanding the complexities of the low carbon economy transition. Furthermore, for financial geographers investigating the state-finance nexus, these results demonstrate both the power of the state to nudge

financial markets, but also its limits, as the market for investment banking services is a global one.

For policymakers looking to become more sophisticated in their approach to accelerate the low carbon transition and the phasing out of fossil fuels, this study suggests that this is also possible by understanding how governments can become active norm managers in addition to regulators. Policymakers should also consider how incentives for climate responsibility can be set through central bank monetary and fiscal policies. One rationale for why that may be advisable is outlined in the recent report of the Bank of England, which shows that climate change can be a serious threat to financial stability (Bank of England, 2018). As the study has shown, it is debt, rather than equity, that constitutes the overwhelming majority of new fossil fuel fundraising. Hence, for investors and social activists seeking to impact fossil fuel investment, engaging with the banks that heavily finance and underwrite fossil fuel debt may provide greater opportunities for impact than engaging with the fossil fuel sector itself. Last but not least, for social activists looking to accelerate the low carbon transition, understanding the role of norm manager of different tiers of government could enhance the effectiveness of the fossil fuel divestment campaign.

Our study is not without its limitations. First of all, it presents the financing dynamics solely in the oil and gas sector. Secondly, it does not propose to analyse whether more stringent environmental policies or divestment commitments affect the cost of capital of oil and gas companies, which is related to the amount of capital that the sector can fundraise. To further test this, it is possible to set-up a company level panel dataset and extend the cost of capital model of Hoepner *et al.* (2016) to include environmental policy and country level divestment commitments in the study of cost of capital. An alternative hypothesis that may affect the results and we could not control for

is that to a certain degree, investment bank oil financing is influenced by the social and political ties between financiers, oil companies and governments (Carroll et al., 2018). In a different research setting, it would be possible to analyse the backgrounds and ties of top oil investment bankers and whether this influences the funding amounts that their banks funnel towards the oil and gas sector. Banks may also reduce their exposure to oil for reputational purposes. Studying this would require further matching investment bank financing data with the statements and policies of each bank (including CSR policies) and analyse whether these materially impact fossil fuel financing. Finally, the study cannot discern whether lower oil and gas financing translates into more investment in low carbon technologies. These are all important areas for further research.

Chapter 3 Appendices

Appendix A.3.1: Top 30 countries in total oil and gas financing by country (2000 – 2015). Data from Dealogic.

Oil & Gas Company Fundraising by Country (2000 – 2015)	Total Fundraising ($bn)	Bank Loans ($bn)	Bond Issuance ($bn)	Equity Issuance ($bn)
United States	3258.84	2286.49	652.35	320.01
Canada	958.19	688.11	144.98	125.10
Russian Federation	336.14	225.06	89.37	21.71
United Kingdom	264.17	114.05	120.09	30.03
Netherlands	244.01	112.19	131.73	0.09
Japan	236.10	216.78	8.68	10.64
China	204.45	38.96	138.89	26.60
Norway	174.89	124.35	34.45	16.08
Mexico	142.33	64.09	76.01	2.22
India	130.36	93.63	19.21	17.52
Switzerland	124.49	115.59	6.67	2.23
France	122.91	15.24	89.64	18.03
Brazil	97.58	43.98	10.41	43.19
Australia	93.00	37.70	8.85	46.45
South Korea	72.61	11.06	59.91	1.64
United Arab Emirates	65.44	45.73	17.19	2.53
Cayman Islands	61.17	1.50	59.67	0.00
Italy	61.12	18.42	26.10	16.60
Singapore	49.41	42.55	5.16	1.69
Virgin Islands (British)	47.85	1.28	46.57	0.00
Malaysia	42.38	24.22	16.90	1.26
Saudi Arabia	42.23	41.34	0.00	0.89
Angola	36.01	36.01	0.00	0.00
Venezuela	32.83	11.93	20.90	0.00
Indonesia	32.46	20.10	10.08	2.29
Thailand	32.27	10.45	20.30	1.52
Qatar	28.90	21.03	6.97	0.89
Kazakhstan	27.75	15.85	8.88	3.02
Spain	27.56	10.18	3.71	13.66

Appendix A.3.2: Country fossil fuel divestment pledges by type of organisation (2008 - 2018). Data from DivestInvest Initiative.

Country	Total Divestment Commitments ($bn)	Financial Organisations Divestment Commitments ($bn)	Governmental Organization Divestment Commitments ($bn)	NGOs, Academic Institutions and Faith Organisations Divestment Commitments ($bn)
Norway	1176.40	85.81	1090.56	0.02
Switzerland	902.29	902.24	0.00	0.05
France	846.13	845.11	0.62	0.40
United States	836.48	647.53	10.85	178.10
Netherlands	807.51	807.51	0.00	0.00
Germany	795.26	790.49	1.38	3.40
Italy	628.72	628.72	0.00	0.00
Sweden	328.33	299.02	27.98	1.33
Australia	150.04	137.60	8.30	4.06
Luxembourg	131.09	131.09	0.00	0.00
UK	66.00	19.10	3.87	43.02
New Zealand	60.96	30.83	29.47	0.66
Denmark	54.97	51.65	1.40	1.92
Austria	18.70	18.20	0.00	0.50
Canada	14.67	14.30	0.00	0.37
Ireland	8.73	0.00	8.48	0.25

Appendix A.3.3: Correlation matrix

	Mean	Sd.	Min	Max.	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9].	[10]	[11]	[12]	[13]
[1] Total.OG.Fundraising.	12784.65	38285.28	0	343128.2													
[2] EPS	1.94	0.98	0.375	4.13	-0.08												
[3] Taxes.	1.44	0.81	0	4	-0.04	0.29***											
[4] Trading.Schemes.	0.88	1.20	0	5.2	0.01	0.45***	0.22***										
[5] FIT.	1.68	1.97	0	6	0.01	0.57***	0.12**	0.13**									
[6] Standards	3	1.66	0	6	-0.03	0.79***	0.12**	0.43***	0.31***								
[7] RDsubsidies	2.11	1.39	0	6	0.01	0.48***	0.16***	0.13**	0.01	0.13**							
[8] OG.Revenue.	134480.3	256336.3	0	1743056	0.34***	0.05	0.15***	0.09*	0.15***	-0.07	0.07						
[9] Env.Patents.	4548.3	11499.7	0.33	82247	0.46***	0.13**	0.36***	0.28***	0.19***	0.09*	0.17***	0.41***					
[10] GDP.Capita.	27620	13592	1895	67056	0.08	0.00	0.44***	0.47***	0.29***	0.00	0.00	0.15***	0.53***				
[11] Oil.Prod.	49072	97841	0	505603	0.46***	-0.15***	-0.17***	-0.14**	-0.14**	-0.12**	-0.07	0.18***	0.11*	-0.31***			
[12] Gas.Prod	2373	5746	0	31405	0.23***	-0.17***	-0.04	0.07	-0.15***	-0.11*	0.09*	0.06	0.27***	0.22***	0.00		
[13] RE.TE.	13.2	11.9	0.4	51.54	-0.02	0.13**	-0.23***	0.04	-0.02	0.07	0.25***	0.01	-0.22***	-0.17***	0.14**	-0.27***	
[14] FF.Divest. Total.	293.7	4263.2	0	88678.4	0.15***	0.05	0.03	0.21***	0.06	0.07	0.01	0.13**	0.18***	0.18***	0.10*	0.07	0.03

Note: The correlation values are given for the orthogonalized variables: Standards, RDsubsidies and Gas.Prod.

4 Going from Zero to One: How Environmental Knowledge and Policy Shapes Start-Up Creation across Green, Brown and Gray Industries

4.1 Introduction

"Doing what we already know how to do takes the world from 1 to n, adding more of something familiar. But every time we create something new, we go from 0 to 1."
(Thiel and Masters, 2014)

The increased societal attention and urgency towards combating climate change and transitioning to a low carbon, resource efficient economy has prompted many actors around the globe to seek solutions to solving environmental issues. In the past decade, entrepreneurs have become instrumental in solving our most pressing societal challenges through business model, technological, financial and social innovation (Malen and Marcus, 2017; York and Venkataraman, 2010).

The underlying mechanisms which enable new technology emergence across time and space have been the focus of both innovation academics and institutional theorists (Vedula et al., 2018). Innovation studies draw the attention to contextual knowledge as one of the most important factors affecting the creation of new firms (Acs et al., 2009; Audretsch, 1995; Audretsch and Keilbach, 2007a). This literature has been linked with the insights from institutional theory which highlights how entrepreneurs are influenced by government policy and regional social norms (Dean and McMullen, 2007; Mason and Brown, 2013; Vedula et al., 2018; York and Lenox, 2014; Zietsma et al., 2018).

Joining these two literature strands is ever more important in the context of the creation of new green start-ups, as we require a holistic understanding of the means through which we can achieve a timely transition to a resource efficient economy. So far, technology and innovation studies engaged with the topic of green entrepreneurship by researching whether knowledge related to environmental management is conducive to

green entrepreneurship. These are mainly empirical studies at the regional level within a single country, predominantly across the US (Malen and Marcus, 2017; Vedula et al., 2018) and Italy (Colombelli and Quatraro, 2017). In addition, the literature does not clarify whether new environmental knowledge has a beneficial role in fostering start-ups beyond the green sector, such as in industries without an environmental goal, or in industries with large environmental externalities.

Studies approaching environmental issue from an institutional angle have linked environmental policy with new venture creation either through frameworks suggesting how policy could influence green entrepreneurship (Reichardt et al., 2016; Zietsma et al., 2018) or as an empirical test linking the presence, but not the stringency, of environmental policies with green start-up creation (Sunny and Shu, 2017; York and Lenox, 2014). The unavailability of cross-country environmental stringency datasets means that the literature provides qualitative assessments on how green entrepreneurs perceive environmental policy (Zietsma et al., 2018) with little or no indication whether environmental policies affect the rate of new venture creation.

There is much common ground between innovation and institutional studies. As far as green innovation is concerned, the common ground has so far been defined by the studies investigating different versions of the Porter hypothesis (PH), which deal more specifically with answering one or more of the following questions: i) whether a more stringent environmental policy hampers innovation effort; ii) whether market-based environmental policies are better at fostering innovation than non-market-based ones; or iii) whether more stringent environmental policies enhance firm or sectoral competitiveness (Ambec et al., 2013; Dechezleprêtre and Sato, 2017). To our knowledge, these studies do not focus on new firm creation, although they extensively link policy outcomes with environmental innovation and new knowledge creation.

In this light, our study makes several contributions to innovation and institutional literature. We analyse the joint influence of new environmental knowledge and environmental policy stringency on green entrepreneurship outcomes, but also on the creation of new ventures that do not have an environmental goal (termed as gray start-ups) and on the creation of ventures that serve sectors with high environmental externalities (termed as brown start-ups, e.g. fossil fuels). Our paper provides cross-country and cross-regional evidence (24 OECD countries and 293 regions from 2001 - 2013) and contributes to institutional theory by extending the literature on PH to include entrepreneurship outcomes.

We find that new environmental knowledge creation at the regional level is highly correlated with the creation of green start-ups, moderately correlated with gray start-ups and uncorrelated with brown (fossil) start-ups. In addition, we find that the more stringent environmental policies are in a country, the less new high growth ventures emerge across all sectors in a given region. The negative policy effect is particularly strong for brown start-ups, which face disruption from a growing renewable sector as well as increased costs of environmental-related compliance. The overall policy effect is explained by market-based policies, while non-market-based environmental policies have no significant effect on new venture creation.

This paper is structured as follows. In section 4.2, we propose a model for explaining the effects of environmental policy and new environmental knowledge on high-growth start-up formation. We ground the model in the literature on environmental entrepreneurship, environmental policy and the knowledge spillover theory of entrepreneurship. Section 4.3 discusses our empirical model, data collection and preparation. Section 4.4 provides descriptive statistics of our panel dataset, while section 4.5 discusses the results of our empirical investigation.

4.2 Theoretical background and hypotheses

In this study we refer to green entrepreneurship as the creation of new ventures that pursue both environmental and economic goals (Isaak, 2016; York et al., 2016). These come from a broad range of sectors that seek the reduction of environmental degradation or promote the responsible use of renewable resources, including: solar, wind, biomass, electric vehicles, storage, smart home solutions, water and wastewater recycling, pollution control solutions among others. The term "grey" entrepreneurs is used to refer to entrepreneurs in industries for which environmental factors are neither major risks nor opportunities (e.g. software start-ups) although they may rely on natural resources. Finally, "brown" start-ups are those that are likely to be heavily impacted by more stringent environmental policies due to their reliance on natural resources and environmental externalities that they produce (e.g. oil and gas entrepreneurs).

The term "environmental policy stringency" is defined as both: "a higher, explicit or implicit, cost of polluting or environmentally harmful behaviour […] for instruments like taxes"(Botta and Koźluk, 2014, pp. 14) as well as incentives for the development of environmental technologies and processes such as feed-in-tariffs or R&D subsidies.

4.2.1 New environmental knowledge and venture creation

Entrepreneurship scholars have mostly focused on the characteristics of individuals which result in a higher propensity of a person to engage in the founding of new ventures (Audretsch and Keilbach, 2007a). The source of entrepreneurial opportunity was largely considered constant across all individuals and entrepreneurship activity was explained by differences in the cognitive ability of people to recognise opportunities (Krueger, 2003). The knowledge spillover theory of entrepreneurship (KSTE), developed by Audretsch (1995) and further refined by Audretsch and Keilbach (2007) and Acs et al. (2009), turned this assumption on its head, by examining how new venture creation is influenced

by the context and source of opportunities, assuming individuals have similar capabilities in recognising them.

KSTE suggests that the main sources of entrepreneurship opportunities are new ideas and knowledge that are created but left uncommercialized. Incumbent firms, universities, research organisations or individual inventors may decide not to commercialise the knowledge that they create given the inherent uncertainty of the payoff associated with pursuing commercial opportunities. Thus, the entrepreneurship opportunity arises from an expected valuation assymetry of uncommercialised knowledge between those who create knowledge and potential entrepreneurs. The valuation assymetry is partly due to the entrepreneurs's higher ability to bear the costs of uncertainty associated with uncommercialised knowledge (Acs et al., 2009; Audretsch and Keilbach, 2007a).

Potential entrepreneurs can come in contact with new and uncommercialised knowledge "[…] by participation in formal R&D partnerships as well as through supplier–customer relationships, professional associations and mobile human capital" (Feldman and Kelley, 2006, pp. 1510) among other channels. However, firms or individuals will not be able to recognise the value of new knowledge and use it to its full benefit, unless they have contextual absoptive capacities (Cohen and Levinthal, 1990). Contextual absorptive capacities can be seen in this sense as prior knowledge in a sector or technology that would help put new knowledge into context.

In a nutshell, KSTE implies that a higher amount of new knowledge created leads to a greater opportunity set for entrepreneurs. This process is moderated by the efficiency of different knowledge spillover chanels as well as the absorptive capacities of individual entrepreneurs. KSTE informs our study in two ways: first, we investigate whether new knowledge related to green technologies results in green entrepreneurship; second, we

explore environmental knowledge spillovers beyond the green sector by testing whether new environmental knowledge shapes start-up creation in gray or brown sectors.

Preliminary evidence from Colombelli and Quatraro (2017) shows that new venture creation in environmental technologies in Italy over the 2009 – 2015 period is positively influenced by new knowledge related to environmental technologies, but not new knowledge relevant for fossil fuel activities. The paper also illustrates that a more diverse local knowledge leads to enhanced environmental start-up creation. These insights are confirmed by Vedula et al. (2018) who study US green entrepreneurship and environmental knowledge pools at the metropolitan statistical area (MSA) legel over the period 1999 – 2010. Vedula et al. (2018) show that knowledge specialisation into green technologies at the MSA level results in a lower likelihood that entrepreneurs pursue green opportunities. This is in line with evidence from Delgado et al. (2010), showing that while clusters of complementary industries are conducive to entrepreneurship, highly specialised clusters exhibit diminished returns to entrepreneurship given high barriers of entry and overcrowding. In light of this literature, we hypothesise that:

H.1a. New regional environmental knowledge is positively related to high-growth green start-up creation.

But do environmental knowledge spillovers result in entrepreneurship outcomes beyond the green sector? Isaak (2016) distinguishes between two types of entrepreneurs in the environmental management context: those who create an environmentally focused business from the start, who embed resource efficient product and services in their core business model; and those who discover "the cost and innovation and marketing advantages […] for greening their existing enterprise" (Isaak, 2016, pp. 82). This suggests that entrepreneurs can take advantage of business models that rely on eco-efficiencies to drive cost reductions and enhanced profitability in the value chains they operate in, without having an explicit environmental goal. Scholars focusing on linking

the financial performance with the eco-efficiency performance of companies across sectors have consistently found that eco-efficiency enhances corporate financial performance, whether it is through better stock market performance or decreased cost of debt (Clark et al., 2014; Derwall et al., 2005; Giacomini and Turner, 2015; Andreas G. F. Hoepner et al., 2011; Ibikunle and Steffen, 2015). Hence, there is a possibility that new environmental knowledge is also conducive to gray entrepreneurship, to the extent to which eco-efficiency can provide profit enhancing opportunities in sectors which are unrelated to the environment. This leads to the following hypothesis:

H.1b. New environmental knowledge is marginally but positively related to gray entrepreneurship.

Taking our inquiry further, are there any reasons to believe that the creation of new environmental knowledge is conducive to new high-growth brown start-ups which operate in sectors which have historically large environmental externalities (e.g. oil and gas)? This link has not been explored so far in the literature. Colombelli and Quatraro (2017) show that the creation of new brown knowledge is not conducive to green entrepreneurship, but do not investigate the determinants of brown entrepreneurship. Brown start-ups have a complementary business model to that of fossil fuel incumbents, mainly in digital technologies for operation and maintenance of oil and gas operations of which they capture a market of c. USD 24 billion (BNEF, 2017). So far, we have not been able to find any evidence that brown entrepreneurs enter the sector to make it more environmentally responsible, hence it is unlikely that new environmental knowledge influences their decision to enter the sector. While the literature does provide some evidence of knowledge spillovers from the green to the brown sector, this tends to happen only at the level of large diversified incumbents which innovate in both fields (Noailly and Shestalova, 2017). In this light, we hypothesize that:

H.1c. New environmental knowledge is not related with brown start-up creation.

4.2.2 Environmental policy stringency and entrepreneurship

Since entrepreneurs are seen as job creators and celebrated as key agents of economic growth (Acs et al., 2016), policy makers have taken great interest in tailoring public policies that promote entrepreneurship (Shane, 2009). While public policies targeted at enabling high-growth entrepreneurship have been explored in more depth (Grilli and Murtinu, 2014; Lerner, 2010; Mason and Brown, 2013), it is less understood how entrepreneurs in emerging high-tech sectors are impacted by government policies which aim to correct environment-related market failures.

The emerging literature on policy mixes for sustainability transitions has partly addressed this topic, but mostly focuses on the policy design process, policy instrument interaction or on conceptualising desirable and undesirable characteristics of a policy mix (Reichardt et al., 2016; Rogge and Reichardt, 2016). The policy mix literature overlooks the goals of different economic agents (e.g. green entrepreneurs vs. diversified utilities) and how these actors may act in accordance with their own agendas, means and motivations (David, 2017). Policies for green entrepreneurship identified in the literature include R&D funding schemes, the creation of innovation platforms, knowledge diffusion networks, SME advice systems, incubators as well as capital injections through government backed low-interest loans to name a few (Kivimaa and Kern, 2016).

In the policy mix literature, entrepreneurs are seen through Schumpeter's (1942) lens, as agents of creative destruction of unsustainable business models. Hence, studies have framed the role of policy for sustainability transitions as catalytic for green entrepreneurs, but also as inhibitive for actors who generate environmental externalities (David, 2017; Kivimaa and Kern, 2016). But are environmental policies catalytic for new venture creation?

The task of establishing the link between environmental policy and entrepreneurship has historically been difficult, mainly due to the unavailability of relative policy stringency measures. Scholars who sought to investigate this relationship statistically have resorted to using variables which can only provide information as to whether a policy instrument is present or not in the policy mix of a particular country, state or region, but not the degree to which these policies are stringent towards polluters or encouraging towards eco-innovators (York and Lenox, 2014). Using the US green building sector as a case study, York and Lenox (2014) find that a higher count of state incentive policies is a positive and significant predictor of entry of diversifying incumbents into the green building sector but had no effect on entries of new firms. One study that does use a measure of stringency, makes use of survey data from only one year to assess the likely factors related to green entrepreneurship (Hörisch et al., 2017). The paper shows that green entrepreneurship opportunities in OECD countries are negatively impacted by high environmental market taxes, which suggests that entrepreneurs cannot meaningfully translate market taxes into a market opportunity ripe for disruption.

Ball and Kittler (2017) provides evidence from interviews with environmental entrepreneurs from the UK, France and Germany and shows that even though more stringent environmental policies (e.g. market taxes) or support mechanisms for low carbon investment like emissions trading schemes have been introduced, these were more effective in supporting large diversified incumbents and utilities rather than promoting entrepreneurship. The study also finds that feed-in-tariffs which allowed for the emergence of community energy initiatives were more conducive towards entrepreneurship in Germany. However, the lack of long-term commitment from the government and constant restructuring of the policy meant entrepreneurs ultimately perceived policy uncertainty as detrimental to their business plans.

The relationship between environmental policy and entrepreneurs is further complicated by other economic agents. Zietsma et al. (2018) show that incumbents can use their political capital to lobby and influence policymakers towards a policy environment favourable to incumbent structures rather than new entrants. Entrepreneurs are hence likely to be trapped in what Pacheco et al. (2010) calls "the green prison", where they face a competitive disadvantage compared to incumbents in conditions where market incentives are set to favour the latter. Pacheco et al. (2010) uses the prisoner's dilemma metaphor to illustrate that potentially green entrepreneurs may face a choice to incur costs related to internalising environmental externalities to the detriment of profitability or pursue profitable goals without necessarily incorporating sustainability considerations in their business models, and hence at the detriment of the collective (society). A complementary view is that of York et al. (2016), who show that the hybrid identity of entrepreneurs as environmentalists and profit-seeking individuals is then reflected in the goals that their ventures pursue and shape their ventures' stakeholder relationships. In this respect, green entrepreneurs with strong environmental motivations may be deterred to start a new venture given the significant costs they may incur to internalise environmental externalities in their business models, but on the other hand, a coherent and stringent environmental action from governments may crowd out entrepreneurs who seek to deliver environmental benefits to society. At the moment, the literature suggests that a new breed of green entrepreneurs is needed, which have the difficult task of seeking to alter the rules of the game, by trying to change norms, property rights and legislation that would reward environmentally friendly practices (Dean and McMullen, 2007; Pacheco et al., 2010).

Sometimes, green entrepreneurs can benefit from the visibility and influence of their financial backers. An example here is Range Fuels and LanzaTech, which benefited

from the public policy engagement of their common venture capital (VC) backer, Khosla Ventures, which alongside other high profile VC funders such as KPCB have engaged in lobbying for favourable policy change towards sustainable energy issues (Center for Responsive Politics, 2018; Pacheco et al., 2010).

Given that the academic literature on the topic is limited in both geographical scope and in its ability to measure environmental policy stringency at either aggregate or individual policy instrument level, we cannot form a hypothesis on the likely impact of environmental policy on green entrepreneurship across our target 24 countries and 293 regions and over 13 years. Furthermore, the academic literature focused on the links between environmental policy and green innovation provides evidence from incumbent organisations and does not clarify how green entrepreneurs may interact with policy. While environmental policy is aimed at encouraging green innovation, there is no direct implication that green entrepreneurs should be the beneficiaries of a more environmentally stringent policy regime, at the expense of, for example, established utilities. On the other hand, there is ample evidence that incumbent organisations do become more eco-innovative in more environmentally stringent policy regimes (Ambec et al., 2013; Dechezleprêtre and Sato, 2017). There is also ample evidence from research on environmental finance, that more eco-innovative incumbent organisations perform better financially with respect to those that do not innovate and as a result their investors can reap significant benefits (Clark et al., 2014; Derwall et al., 2005; Andreas G. F. Hoepner et al., 2011; Ibikunle and Steffen, 2015).

In this respect, our study proposes to test the impact of environmental stringency on green entrepreneurship, with the expectation that this can be positive, negative or non-significant depending on whether entrepreneurs can seize opportunities as a result of more progressive environmental policies, or whether entrepreneurs are trapped in the

"green prison" where these policies, while reaching their environmental goals, are disadvantageous towards entrepreneurs (Pacheco et al., 2010).

On the other hand, we do expect that a more stringent environmental policy will strongly and negatively impact brown entrepreneurs, given that the primary goal of environmental policy is to penalise economic agents operating in sectors with large environmental externalities, in addition to enabling eco-innovation (David, 2017; Kivimaa and Kern, 2016). We also expect that environmental regulation may result in increased operational costs across sectors which rely on natural resource intensive supply chains (Cojoianu et al., 2015) and hence more stringent environmental policy may result in increased operational costs for gray entrepreneurs. Hence, we hypothesise that:

H.2a. A more stringent environmental policy regime is negatively related to brown entrepreneurship.

H.2b. A more stringent environmental policy is marginally but negatively related to gray entrepreneurship.

To provide more context on the likely effect of different policy instruments across sectors, we draw insights from the PH literature, which looks at the effects of environmental policy on innovation (Ambec et al., 2013; Dechezleprêtre and Sato, 2017). In particular, we ask whether whether flexible market-based policies[9] are more adept at enhancing innovation at the firm and sectoral level than non-market policies.

For a panel of European countries, Fabrizi et al. (2018) show that market-based policy instruments, in conjunction with participation in green European academic and public research networks, are more effective in encouraging patenting in renewable energy than non-market-based policy instruments over the period 2002 – 2013. Morales-

[9] "Market-based instruments seek to address the market failure of 'environmental externalities' either by incorporating the external cost of production or consumption activities through taxes or charges on processes or products, or by creating property rights and facilitating the establishment of a proxy market for the use of environmental services." – OECD, 2007, Business and the Environment: Policy Incentives and Corporate Responses, OECD, Paris.

Lage et al. (2016), in a similar exercise across 14 OECD countries between 1990 – 2011, show that more stringent environmental regulations have a positive influence on R&D expenditure, patent applications and total factor productivity.

The literature thus suggests that market-based policies are more effective than non-market-based policies in driving eco-innovation and in placing the financial incentives for incumbents to incorporate environmental considerations in their business models. We expect that there will also be a different effect of market vs. non-market-based policy instruments on new venture creation.

H.2c. Market-based policies will be more strongly and negatively related to brown and gray entrepreneurship than non-market-based policies.

4.3 Data and methodology

4.3.1 Dependent variables

New high-growth technology start-up ventures

The dependent variable is comprised of the yearly count of new high technology ventures across 293 regions in 24 OECD countries founded between 2001 - 2013. To illustrate how different entrepreneurship sectors are impacted by different government policies, we study new entries in green, brown and gray sectors as well as the overall entrepreneurship ecosystem. We use a paid database subscription to Crunchbase[10], a leading provider of intelligence for investors in high-growth technology start-ups around the world, to map the high-tech start-ups founded between 2000 – 2016 (176,994 in total) by region and sector. While we do not have year-on-year revenue data to shortlist start-ups on their revenue growth rates, we consider that being visible on the Crunchbase platform and consequently on the radars of venture capitalists and institutional investors around the world is a proxy for high-growth potential.

[10] https://www.crunchbase.com/

To identify the sectors of interest that new entrants operate in, we mapped the technology sector provided by Crunchbase with the Sustainable Industry Classification System (SICS) provided by the Sustainability Accounting Standards Board (SASB). To further enhance the dataset, we included a database of 6,831 corporations which have environmental aims in their articles of incorporation (list of B corporations and public benefit corporations provided by B Lab[11]) which we used to further identify companies in the green sector in Crunchbase. The technologies that comprise the green, brown and gray sectors are outlined in **Table 4.1**.

[11] https://www.bcorporation.net/

Table 4.1: Industry classification matching. Source: authors.

SASB Industry Classification	Crunchbase Classification	Paper Terminology
Renewable Resources, Alternative Energy & Infrastructure (Utilities and Waste Management).	Battery, Biofuel, Biomass Energy, Clean Energy, CleanTech, Electric Vehicle, Electrical Distribution, Energy Efficiency, Energy Management, Energy Storage, Environmental Consulting, Environmental Engineering, Fuel Cell, Green Building, Green Consumer Goods, GreenTech, Paper Manufacturing, Pollution Control, Power Grid, Renewable Energy, Smart Building, Smart Home, Solar, Sustainability, Timber, Waste Management, Water, Water Purification, Water Transportation, Wind Energy, Wood Processing, Recycling	Green
Non-Renewable Resources	Fossil Fuels, Fuel, Mineral, Mining Technology, Natural Resources, Oil and Gas, Precious Metals, Mining	Brown
Healthcare, Financials, Technology and Communications, Transportation, Services, Consumption, Infrastructure (Infrastructure and Real Estate).	Software, Biotech, Healthcare, Telecommunications, Real Estate and other sectors excluding the ones above.	Gray

We use the yearly count of new entrants by technology and region. The mapping of all the high-growth start-ups by region was done manually using a company's incorporation address and a mapping tool provided by the OECD which allows us to match company addresses with Territorial Level 2 or TL2 regions of OECD countries (OECD, 2018). This allows for comparability internationally given that national statistical offices use the OECD classification to collect different policy relevant datasets and governments use these to set regional policies.

4.3.2 Independent variables

The variables below seek to capture new environmental knowledge per region (as measured by patent applications) and environmental policy stringency (as measured by OECD environmental indices). We further include the number of research institutes per region (government, academia and corporate R&D) to capture the knowledge generation capacity of a region.

Environmental knowledge

We use regional patent applications as a proxy for new regional environmental knowledge. Regional green patent data was collected from the OECD REGPAT database which allows for quantification of the innovation output over more than 2,000 TL3

regions in the OECD and across several technologies including environmental technologies (Maraut et al., 2008). We aggregate these to the TL2 level to match the high-growth start-up dataset. The OECD employs robust patent search methodologies to identify all the patent applications to the EPO, USPTO and JPO as well as those filed under the Patent Cooperation Treaty (PCT)(OECD, 2016). The patents belong to six top-level environmental technology categories: i) capture, storage, sequestration or disposal of greenhouse gases, ii) climate change mitigation technologies related to buildings, iii) climate change mitigation technologies related to energy generation, transmission or distribution, iv) climate change mitigation technologies related to transportation, v) environmental management and vi) water-related adaptation technologies (Haščič and Migotto, 2015).

Patents are an imperfect measure of regional or country innovation given that it cannot capture those innovations that are not patentable or inventions that are not patented by their inventors. In addition to this, not all patents are used for commercial purposes. However, patent data offer the intermediate outputs of the innovation cycle, they are widely available and can be easily classified to match the technology sector of interest. In accordance with Fabrizi et al. (2018), we use environmental patent applications rather than patents granted since the patent application event reflects much more accurately the timeframe of new knowledge creation. The patent data is further grouped by the region of residence of the inventors and are represented as a fractional count of the country's patents. We round these by region and use the data as non-negative count data in our econometric model.

OECD environmental policy stringency

The policy variables we use in this study are the economy wide environmental policy stringency (EPS) indices constructed by the OECD which cover 29 OECD

countries between 1990 – 2012. The EPS composite indices are obtained from granular indicators at the individual instrument level by conducting three levels of aggregation. First, the stringency of individual policy instruments (e.g. wind feed-in-tariffs) are aggregated in policy instrument categories such as feed-in-tariffs, taxes or R&D subsidies. Next, policy instrument categories are grouped into market and non-market policy indices which are finally aggregated into a composite indicator of environmental policy stringency at the country level.

Table 4.2: Environmental Policy Stringency indices. Four aggregation levels. Source: Botta and Koźluk (2014).

EPS Level I	EPS Level II	EPS Level III	EPS Level IV
EPS Aggregate	Market	Taxes	CO_2, NO_x, SO_x, Diesel
		Trading Schemes	CO_2, Renewable Energy Certificates, Energy Efficiency Certificates.
		Feed-in-Tarriffs (FITs)	Solar, Wind
		Deposit and Refund Schemes (DRS)	Deposit and Refund Schemes
	Non-Market	Standards	Emission Limit Values: NO_x, SO_x and PM_x, and Sulphur content limit.
		R&D Subsidies	Government R&D Expenditure on Renewable Energy

Our analysis focuses on levels I, II and III of EPS to provide both an aggregate and granular assessment of the relative impact of policy instruments as well as policy mixes on high-growth entrepreneurship rates. We study the effects of country level environmental policies on regional entrepreneurship given that environmental policy decision making is made at the national level whereas entrepreneurship is highly dependent on clusters and regional characteristics. For federal countries in our dataset (e.g. US States or Canadian Provinces), the country level EPS at different levels is obtained as a weighted average of state-level EPS based on a state's share of a country's total energy generation. In this way the index also takes into account the relative influence of regions where these do have a real influence on regional environmental policy.

Research institutes

To further test the KSTE and how it applies to regions and the interactions between research institutions and entrepreneurship, we map the Global Research Identifier Database (GRID)[12] which provides the addresses of over 85,000 research institutes globally, with our database at the regional TL2 level. The research institutes include company R&D institutions, educational institutions (e.g. universities), government R&D laboratories as well as NGOs which conduct or have high influence over the diffusion of scientific knowledge.

4.3.3 Control variables

Further control variables for which we have strong theoretical grounding to include are listed in **Table 4.3** alongside with the dependent and key independent variables.

Table 4.3: Variables description and data sources.

Variable Name	Variable Description	Data source
Green	Count of new high-growth green (environmental) ventures per region per year.	Crunchbase, BLab and SASB.
Brown	Count of new high-growth brown (fossil fuel) ventures per region per year.	Crunchbase and SASB.
Gray	Count of new high-growth gray ventures per region per year.	Crunchbase and SASB.
All	Count of all new high-growth ventures per region per year.	Crunchbase.
Environmental_Knowledge	Fractional green patent count per region per year.	OECD REGPAT, OECD iLibrary.
Environmental Policy Stringency (EPS)	Country level annual index.	OECD iLibrary – Regional Statistics.
Regional Start-Up Funding	Total equity and debt funding to high-growth start-ups per region per year.	Crunchbase.
Regional GDP / capita	Regional GDP / capita	OECD iLibrary – Regional Statistics.
Research Institutes	Number of regional R&D institutions in a given year.	GRID
R&D % of GDP	R&D as % of GDP – annual country figure.	Passport Monitor.
Ren Energy % of Tot. Energy	Renewable energy as percentage of primary energy supply.	OECD Statistics.
Renewable Industry Tilt	The ratio between the number of listed renewable and the number of listed renewable non-renewable energy companies listed on the country's stock exchange in a given year as a proxy for the dominance of either green or fossil fuel incumbent structures	SASB

[12] https://www.grid.ac/

4.3.4 Model specification

Our analysis is conducted at the regional level, with data organised in a balanced panel between 2001 – 2013. The start-up entry dependent variables across of three sectors (green, brown and gray) is a non-negative count integer. The model residuals exhibited overdispersion and violated normality assumptions and hence, in line with the work of York and Lenox (2014), we employ a random effects model. Allison and Waterman (2002) show that a fixed effects estimator is biased for a negative binomial model and cannot control for varying covariates. To further control for temporal variations in our models, we include year dummy variables which we do not report in the results. We further conduct robustness tests which cluster the standard errors of coefficients at the regional level (Petersen, 2008).

All regressors in our models are lagged. The main results have a 1-year lag, but for robustness purposes we test alternative specifications including a longer lag for environmental patents.

The full log-linear models we estimate can be expressed by the following equation at different policy granularity levels, where μ_t is the time effect and $\varepsilon_{i,t}$ is the stockastic error.

$$New\ Ventures_{i,t} = \exp[(\beta_1 * \ln(Environmental\ Knowledge_{i,t-1}) + \beta_2 * ln(EPS_{i,t-1}) +$$
$$+ \beta_3 * ln(Research\ Institutes_{i,t-1}) + \beta_4 * \ln(Start - Up\ Funding_{i,t-1}) +$$
$$+ \beta_5 * \ln(GDP\ per\ Capita_{i,t-1}) + \beta_6 * ln(R\&D\ as\ \%\ of\ GDP_{i,t-1}) +$$
$$+\beta_7 * ln(Ren\ Energy\ \%\ of\ Tot\ Energy_{i,t-1}) + \beta_7 * ln(Renewable\ Industry\ Tilt_{i,t-1}) + \mu_t + \varepsilon_{i,t}]$$

4.4 Descriptive statistics

The purpose of this section is to illustrate the importance of the regional level of analysis given that the geography of high-growth ventures is highly influenced by the geography of technology clusters (Braunerhjelm and Feldman, 2006; Delgado et al.,

2010). We also aim to provide further context into the green, gray and brown entrepreneurship sectors worldwide.

Overall, the number of new high growth gray start-ups across the 24 OECD countries has increased significantly from over 4,000 companies in the year 2000 to a peak of over 14,000 in 2012 and 2013. This was followed by a sharp decrease in gray high-growth start-up rates to just under 4,000 in 2016 (**Figure 4.1**). The same pattern applies for green and fossil fuel industries. While start-up founding rates have decreased since 2013, total equity and debt financing to OECD start-ups has reached a new high in 2016 of over US$ 194 billion. This implies that start-ups are staying private for longer and venture capital and private equity funding has focused more on growth and late stage financing.

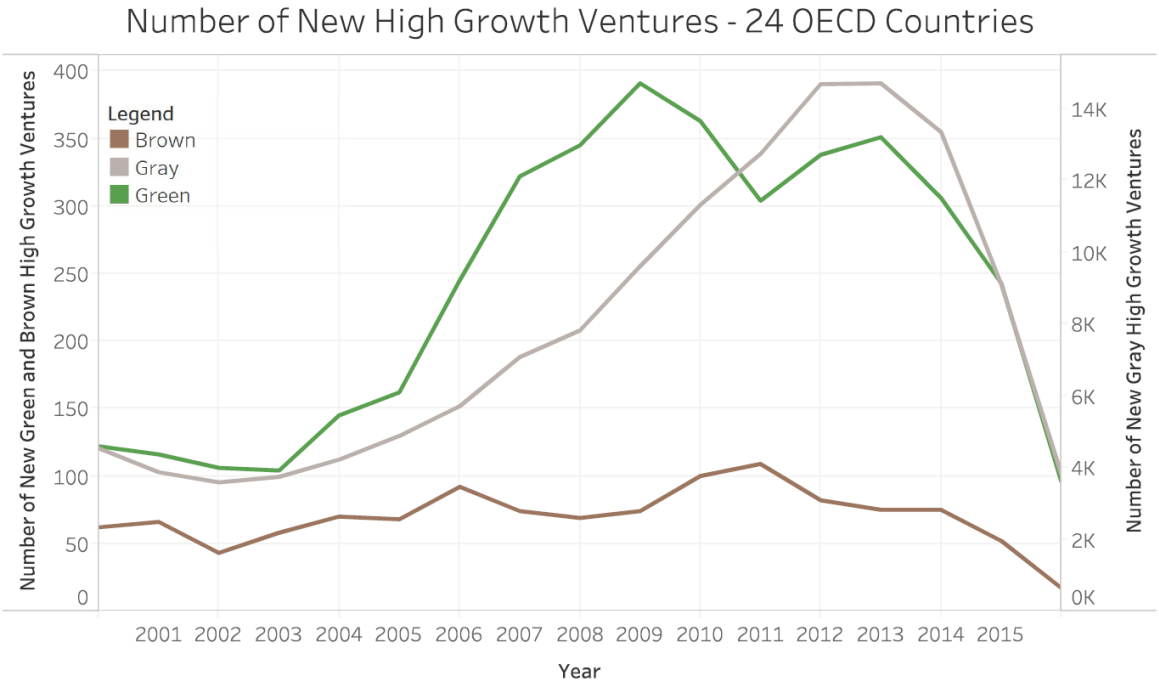


Figure 4.1: High-growth start-up entries and funding Statistics. Source: authors based on data from Crunchbase.

Table 4.4: Country and regional cumulative high growth start-up entry between 2000 and 2013. For US states distribution we display only states with more than 20 green start-ups cumulatively. For OECD regional (excluding US) statistics we display only regions with more than 14 cumulative green start-ups. Tables are sorted descending by total number of green start-ups.

Country Distribution of New High Growth Ventures (2000 to 2013)

Country	Gray	Green	Brown
United States	68,741	2,182	547
United Kingdom	10,040	292	88
Canada	4,746	179	204
Germany	2,938	90	11
Australia	2,384	78	42
France	2,586	77	17
Spain	2,868	73	6
Netherlands	1,465	61	8
Ireland	1,472	51	11
Sweden	1,006	42	8
Denmark	632	30	1
Italy	890	30	1
Finland	648	21	0
Belgium	521	17	3
Austria	377	15	0
Mexico	345	15	1
Norway	295	13	25
Japan	698	9	2
Portugal	120	7	1
Greece	170	3	3
Poland	522	3	0
Hungary	130	2	0
Czech Republic	230	1	0
Slovak Republic	70	1	1

US States Distribution of New High Growth Ventures (2000 to 2013)

Region	Gray	Green	Brown
California	21,581	695	58
Texas	3,707	172	203
Massachusetts	3,415	170	6
New York	8,231	150	35
Colorado	1,891	84	38
Illinois	2,902	68	6
Washington	2,323	67	6
Florida	3,126	59	13
Pennsylvania	1,698	58	16
Georgia	1,575	44	5
North Carolina	1,172	41	4
Arizona	1,015	37	8
Ohio	1,097	37	11
Oregon	827	37	4
Minnesota	742	30	5
New Jersey	1,406	30	7
Maryland	958	29	5
Michigan	848	29	5
Virginia	1,388	28	2
Connecticut	632	26	3
District of Columbia	687	24	2
Tennessee	794	21	8
Utah	838	21	5
Nevada	650	20	9

OECD Regional (Excluding US) Distribution of New High Growth Ventures (2000 to 2013)

Region	Gray	Green	Brown
Greater London	5,406	98	28
Ontario	2,410	74	32
South East England	1,247	53	16
British Columbia	1,072	50	69
Southern and Eastern	1,347	48	8
Île-de-France	1,725	44	11
West-Nederland	1,151	42	5
New South Wales	1,089	31	7
Scotland	411	28	17
East of England	584	24	8
Bavaria	618	22	1
Catalonia	873	22	1
Madrid	925	22	3
Berlin	931	20	3
Quebec	689	20	13
Stockholm	595	20	4
Victoria	706	20	10
Alberta	334	19	80
Capital (DK)	447	17	1
Yorkshire and The Humber	307	17	5
North West England	624	16	6
South West England	428	15	2
Helsinki-Uusimaa	485	14	0

Over the 2000 – 2013 period, the US claims over 66% of the total number of new high growth green (2,182) and gray start-ups (68,741) and over 55% of new fossil fuel start-ups worldwide. New high growth green start-ups in California represent over 30% of the US total new green cohort over the 2000 – 2013 period, as well as 17% out of the OECD's new green ecosystem. This is a consequence of California's dominance in the technology and entrepreneurship space for a long time and the willingness of many venture capitalists to finance the first movers in the cleantech venture space.

The UK follows with 292 new green start-ups which is just below 9% of the cumulative number of high-growth green start-ups across the OECD, with Greater London and South-East England are the first and third regions by number of new green entrepreneurs across the OECD excluding the US. The geography of green entrepreneurship is influenced by the geography of other more established technology clusters as well as by the characteristics in the natural environment, particularly for technologies such as solar, wind and tidal energy generation (Knight, 2012). As the new cohort of green entrepreneurs has been transitioning from founding capital intensive infrastructure businesses to starting capital light software companies (Bachher et al., 2014; Gaddy et al., 2017), physical geography is likely to be less important as software scales seamlessly across geographies.

The fossil fuel start-up sector is very much clustered around natural resource rich regions and countries where the oil and gas industry has established itself for a long time. Brown start-ups have a complementary business model to that of fossil fuel incumbents, mainly in digital technologies for operation and maintenance of oil and gas operations of which they capture a market of c. USD 24 billion (BNEF, 2017). The regions with the highest number of fossil fuel start-ups over the 2000 – 2013 period are: Texas (US) -203; Alberta, British Columbia and Ontario (Canada) with 80,69 and 32 high growth brown

start-ups respectively. Western Australia and Scotland host 19 and 17 new brown start-ups respectively. The geographic distribution of new start-ups is positively correlated with that of new regional funding patterns which are further illustrated in **Appendix A.4.1**.

4.5 Synthesis of results

Is environment related knowledge conducive to a greener entrepreneurship sector? Do entrepreneurs find enhanced opportunities because of more stringent environmental policies? Models 1a-d in **Table 4.5**, illustrate how our control variables affect new high-growth start-up rates across sectors. The availability of equity and debt start-up funding has a positive and significant coefficient across sectors but seems to be more important in our niche industries (green: $\beta=0.16$, $p<.001$; brown: $\beta=0.13$, $p<.01$). Regional GDP per capita as well as country R&D expenditure as percentage of GDP are strongly related to high growth start-up entry across all sectors. Initial evidence for the KSTE is that the number of research institutes by region is positively and significantly related to new venture creation across all sectors. The proportion of renewable energy from total energy supply is not significant for either gray or brown start-up entry, but is significant and negative for green start-ups ($\beta=-0.19$, $p<.1$). The degree to which the country's incumbent landscape is tilted towards renewable energy or fossil fuel incumbents (captured through the variable Ren_Industry_Tilt) is not associated with the overall, gray or green start-up rates, but it is negative and statistically significant for fossil-fuel entrepreneurs ($\beta=-2.76$, $p<.01$).

Table 4.5: Control variables and new knowledge stocks models.

	Control Variables Only				New Environmental Knowledge Stocks			
	All	**Gray**	**Green**	**Brown**	**All**	**Gray**	**Green**	**Brown**
	Model 1a	**Model 1b**	**Model 1c**	**Model 1d**	**Model 2a**	**Model 2b**	**Model 2c**	**Model 2d**
Environmental_Knowledge					0.05**	0.05*	0.18***	0.00
					(0.02)	(0.02)	(0.05)	(0.08)
Start_Up_Funding	0.03***	0.04***	0.16***	0.13**	0.03***	0.04***	0.15***	0.13**
	(0.01)	(0.01)	(0.03)	(0.04)	(0.01)	(0.01)	(0.03)	(0.04)
GDP_Capita	0.48***	0.55***	1.32***	0.85*	0.48***	0.54***	1.21***	0.85*
	(0.12)	(0.12)	(0.23)	(0.38)	(0.12)	(0.12)	(0.23)	(0.38)
Research_Institutes	0.83***	0.84***	0.69***	0.76***	0.79***	0.80***	0.56***	0.76***
	(0.05)	(0.05)	(0.07)	(0.11)	(0.06)	(0.06)	(0.07)	(0.13)
R&D % of GDP	1.29***	1.14***	0.61*	1.60**	1.21***	1.07***	0.37	1.59**
	(0.16)	(0.16)	(0.29)	(0.52)	(0.16)	(0.16)	(0.29)	(0.53)
Ren Energy % of Tot. Energy	-0.02	-0.04	-0.19^	0.08	-0.04	-0.06	-0.17	0.08
	(0.05)	(0.05)	(0.11)	(0.17)	(0.05)	(0.05)	(0.11)	(0.17)
Ren_Industry_Tilt	0.02	0.07	0.27	-2.76**	0.04	0.08	0.09	-2.77**
	(0.15)	(0.15)	(0.36)	(0.89)	(0.15)	(0.15)	(0.37)	(0.90)
(Intercept)	-8.52***	-9.10***	-18.88***	-16.85***	-8.35***	-8.93***	-17.45***	-16.84***
	(1.16)	(1.17)	(2.28)	(3.81)	(1.15)	(1.16)	(2.30)	(3.84)
AIC	16630.50	16402.98	4997.04	2561.62	16625.66	16398.36	4986.28	2563.62
BIC	16761.65	16534.13	5128.19	2692.77	16763.05	16535.75	5123.67	2701.01
Log Likelihood	-8294.25	-8180.49	-2477.52	-1259.81	-8290.83	-8177.18	-2471.14	-1259.81
Num. obs.	3809	3809	3809	3809	3809	3809	3809	3809
Num. groups: Regions.	293	293	293	293	293	293	293	293

***p < 0.001, **p < 0.01, *p < 0.05, ^p < 0.1. Standard errors in parentheses.

Models 2a-d assesses the relationship between start-up rates and new environmental knowledge across the different start-up types. As hypothesised, we find a positive and significant correlation of environmental knowledge for green start-ups (β=0.18, p<.001) but no significant relationship with brown start-ups (H.1a-c). We also find evidence for "accidentally" green entrepreneurs (Isaak, 2016), in that new environmental knowledge has a small albeit positive and significant effect on new gray start-up formation (β=0.05, p<.05) (H.1b).

Our findings support the general assumption of the knowledge spillover theory of entrepreneurship (Audretsch and Keilbach, 2007a), that higher stocks of new environmental knowledge are conducive to higher green entrepreneurship rates (Colombelli and Quatraro, 2017). We can provide further nuance to this by showing how the strength of environment-related knowledge spillovers fades when the goal and business model of start-ups have no or marginal intersection with environmental issues as well as how it seems to be completely irrelevant in the case of brown start-ups. This has important implications on the way policymakers think about sustainability transitions as a process not just towards a greener economy, but also away from fossil fuels. New environmental knowledge does not seem to be a motivating factor for potential brown entrepreneurs, which means that it is unlikely that entrepreneurs may be able to "green" the incumbent fossil fuel sector.

We further analyse the effect of the country aggregate environmental policy stringency indicator on new venture creation in models 3a-d and we find that overall, more stringent environmental policy correlates with a smaller propensity of the founding of high-growth ventures across the board. The results are negative and significant (gray – β= -0.31, p<.001; green – β=-0.42, p<.05; brown – β=-0.87, p<.05) (H.2a,b). Looking at the difference between policy mixes which employ more stringent market vs. non-market

instruments (models 4a-d), we find that stringent market environmental policies have a negative statistically significant correlation with start-up rates across all sectors, particularly for brown start-ups (H.2c). Non-market-based environmental policies have no statistically significant correlation with either green or brown new venture rates, but they do have a negative and statistically significant correlation with gray start-up formation (β=-0.16, $p<.01$).

The policy effects viewed from an individual instrument perspective (models 5a-d) show a significant negative association between market taxes and brown start-ups (β=-1.07, $p<.001$), no association between market taxes and green start-ups, and a positive significant association with gray start-ups. The implication of this is that higher environmental taxes create less opportunities for brown entrepreneurs and may create more gray start-ups, potentially related to compliance functions. Market trading schemes have a significant negative association with brown entrepreneurs (β=-0.46, $p<.01$), and no significant correlation with other start-up types. Feed-in-tariffs on the other hand have a negative and statistically significant relationship with new start-up creation across sectors. Deposit-and-refund schemes (DRS), given their niche application to waste management do not seem to be associated with new start-up formation. We also find a weak negative correlation between non-market standards and R&D subsidies on one side and gray entrepreneurship on the other.

Table 4.6: Environmental policy effects at the aggregate, market and non-market and granular policy instrument level.

	Aggregate Country Policy Stringency Effects				Market vs. Non-Market Policy Effects				Individual Policy Instrument Effects			
	All	Gray	Green	Brown	All	Gray	Green	Brown	All	Gray	Green	Brown
	Model 3a	Model 3b	Model 3c	Model 3d	Model 4a	Model 4b	Model 4c	Model 4d	Model 5a	Model 5b	Model 5c	Model 5d
EPS_Aggregate	-0.32***	-0.31***	-0.42*	-0.87*								
	(0.06)	(0.06)	(0.19)	(0.34)								
Market_EPS					-0.16***	-0.12**	-0.33*	-1.02***				
					(0.04)	(0.04)	(0.13)	(0.19)				
Non_Market_EPS					-0.14**	-0.16**	-0.08	0.21				
					(0.05)	(0.05)	(0.17)	(0.26)				
Market_Taxes									0.10*	0.13**	0.12	-1.07***
									(0.05)	(0.05)	(0.14)	(0.21)
Market_Trading_Schemes									-0.04	-0.03	-0.03	-0.46**
									(0.03)	(0.03)	(0.10)	(0.17)
Market_FIT									-0.07***	-0.06**	-0.16**	-0.18^
									(0.02)	(0.02)	(0.06)	(0.10)
Market_DRS									0.10	0.10	-0.15	-0.37
									(0.07)	(0.07)	(0.21)	(0.39)
Non_Market_Standards									-0.06	-0.07^	0.10	0.12
									(0.04)	(0.04)	(0.13)	(0.20)
Non_Market_RD_Subsidies									-0.07^	-0.06^	-0.17	-0.19
									(0.04)	(0.04)	(0.13)	(0.23)
Environmental_Knowledge	0.04*	0.04*	0.17***	-0.01	0.04*	0.04*	0.18***	0.02	0.04*	0.04^	0.18***	-0.00
	(0.02)	(0.02)	(0.05)	(0.08)	(0.02)	(0.02)	(0.05)	(0.08)	(0.02)	(0.02)	(0.05)	(0.08)
Start_Up_Funding.	0.04***	0.04***	0.15***	0.14***	0.04***	0.04***	0.15***	0.15***	0.04***	0.04***	0.15***	0.15***
	(0.01)	(0.01)	(0.03)	(0.04)	(0.01)	(0.01)	(0.03)	(0.04)	(0.01)	(0.01)	(0.03)	(0.04)
GDP_Capita	0.54***	0.60***	1.22***	0.89*	0.54***	0.60***	1.21***	0.89*	0.51***	0.57***	1.23***	0.92**
	(0.12)	(0.12)	(0.22)	(0.37)	(0.12)	(0.12)	(0.22)	(0.36)	(0.12)	(0.12)	(0.23)	(0.35)
Research_Institutes	0.81***	0.81***	0.56***	0.75***	0.81***	0.82***	0.56***	0.73***	0.77***	0.78***	0.55***	0.78***
	(0.05)	(0.05)	(0.07)	(0.12)	(0.06)	(0.06)	(0.07)	(0.12)	(0.06)	(0.06)	(0.07)	(0.12)
R&D % of GDP	1.08***	0.94***	0.39	1.54**	1.02***	0.94***	0.28	0.84^	1.08***	0.98***	0.40	1.28*
	(0.16)	(0.16)	(0.29)	(0.52)	(0.17)	(0.17)	(0.30)	(0.50)	(0.17)	(0.17)	(0.32)	(0.55)
Ren Energy % of Tot. Energy	-0.09^	-0.11*	-0.19^	0.06	-0.08	-0.11*	-0.18	0.05	-0.10^	-0.14*	-0.15	0.12
	(0.05)	(0.05)	(0.11)	(0.17)	(0.05)	(0.05)	(0.11)	(0.16)	(0.05)	(0.05)	(0.11)	(0.17)
Ren_Industry_Tilt	0.10	0.14	0.18	-2.64**	0.07	0.13	0.11	-3.18***	0.08	0.15	0.18	-3.15***
	(0.15)	(0.15)	(0.37)	(0.91)	(0.15)	(0.15)	(0.37)	(0.94)	(0.15)	(0.16)	(0.37)	(0.92)
(Intercept)	-8.53***	-9.10***	-17.19***	-16.30***	-8.55***	-9.08***	-16.99***	-15.74***	-8.32***	-8.87***	-17.72***	-15.76***
	(1.14)	(1.16)	(2.27)	(3.75)	(1.14)	(1.16)	(2.25)	(3.56)	(1.15)	(1.16)	(2.30)	(3.54)
AIC	16594.80	16371.08	4983.54	2559.02	16601.62	16378.82	4983.58	2539.34	16598.64	16371.16	4988.06	2534.10
Log Likelihood	-8274.40	-8162.54	-2468.77	-1256.51	-8276.81	-8165.41	-2467.79	-1245.67	-8271.32	-8157.58	-2466.03	-1239.05
Num. obs.	3809	3809	3809	3809	3809	3809	3809	3809	3809	3809	3809	3809

***p < 0.001, **p < 0.01, *p < 0.05, ^p < 0.1. Standard errors in parentheses.

While we expected that brown entrepreneurs would be negatively and strongly impacted by more stringent policies, it was not entirely expected that it would be the same with those entrepreneurs seeking high-growth opportunities in the cleantech sector. This finding supports the qualitative findings of Zietsma et al., (2018) that green entrepreneurs can be discouraged by a policy regime shaped by incumbent interests, although in principle the new policy regime may seem more environmentally stringent. The expectation that environmental policy draws the attention and ultimately specialisation of incumbents towards eco-efficiency opportunities may increase competition for green entrepreneurs.

4.6 Robustness tests

To further validate our approach, we conduct several robustness tests. First, we run the models without California as well as without the US to rule out the possibility that these locations do not drive our results. The results are robust in these new specifications. Second, the results are also robust when we use longer lags for environmental patents and when we employ total patents[13] instead of environmental patents, as a measure of total regional knowledge. We also re-run the main models with standard errors clustered at the regional level and find that the results hold (Petersen 2008, see Table 4.9).

To test the validity of the policy results, we obtain two alternative cross-country environmental policy indices from a commercial environmental and social research provider, oekom research[14]. The two indices measure government proactiveness and commitment in addressing environmental issues (measured by the variable oekom_Env_Institutional_Capacity) and air emissions stringency and levels (measured

[13] Coded in the same way from OECD REGPAT.
[14] oekom research AG provides environmental and social performance assessments of countries and companies for the use of institutional investors in their investment process - http://www.oekom-research.com/

by the variable oekom_Air_Emissions). The coverage of the indices is for the period 2006 to 2011 for the 24 countries. **Table 4.7** shows results that are in line with our investigation of the OECD environmental policy stringency effect, where a more stringent air emissions policy regime is strongly negatively correlated with brown entrepreneurship and a seemingly more proactive policy regime in addressing environmental issues is negatively correlated with green and gray entrepreneurship. However, these indices are created using different methodologies and for different audiences (in this case investors on public markets) so slight discrepancies are expected.

Finally, we test the environmental policy stringency hypotheses on an alternative entrepreneurship dataset which measures the total number of new businesses in a region. The business demography dataset is collected by the OECD from national level statistical offices and has a coverage of 14 countries and 180 regions for the period 2008 – 2013. We do so to check whether our results on high-growth entrepreneurship are applicable more broadly (i.e. for new businesses that do not go past the small-to-medium enterprise stage) as well as to highlight where these may differ. **Table 4.8** shows a negative correlation of non-market-based policies with new start-ups, and a relatively weaker but positive correlation of market-based policies with overall entrepreneurship. This shows that when considering the entire gray entrepreneurship ecosystem, while overall results may hold, the effect of market-based policies can be different for SME gray entry compared to high-growth gray entries. It also suggests that although market-based policies may encourage the entry of a broad set of entrepreneurs, in the long term these may limit the growth and innovation prospects of new entrants. This point becomes apparent when comparing model 7b (all new business entries - **Table 4.8**) with model 4a (high growth entrepreneurship cohort - **Table 4.6**).

Robustness Tests

Table 4.7: Alternative environmental policy stringency effects on high growth entrepreneurship.

	All	Gray	Green	Brown
	Model 6a	**Model 6b**	**Model 6c**	**Model 6d**
Environmental_Knowledge	0.06*	0.06*	0.17**	0.04
	(0.03)	(0.03)	(0.06)	(0.11)
oekom_Env_Institutional_Capacity	-0.72**	-0.62**	-1.99***	-0.93
	(0.23)	(0.23)	(0.40)	(0.73)
oekom_Air_Emissions	0.24**	0.23**	0.60*	-0.94*
	(0.09)	(0.09)	(0.25)	(0.45)
Start_Up_Funding.	0.05***	0.05***	0.24***	0.29***
	(0.01)	(0.01)	(0.04)	(0.06)
GDP_Capita	0.46**	0.74***	0.85***	0.49
	(0.16)	(0.17)	(0.23)	(0.47)
Research_Institutes	0.84***	0.82***	0.42***	0.52***
	(0.06)	(0.06)	(0.07)	(0.15)
R&D % of GDP	0.29	0.07	-0.50	0.37
	(0.24)	(0.24)	(0.31)	(0.65)
Ren Energy % of Tot. Energy	-0.14	-0.16^	0.02	0.20
	(0.09)	(0.09)	(0.12)	(0.21)
Ren_Industry_Tilt	0.20	0.34	0.36	-3.46**
	(0.26)	(0.26)	(0.41)	(1.20)
(Intercept)	-6.39***	-9.19***	-10.86***	-9.50^
	(1.61)	(1.76)	(2.51)	(5.02)
AIC	8781.66	8667.88	2823.94	1299.76
BIC	8874.68	8760.90	2916.96	1392.78
Log Likelihood	-4373.83	-4316.94	-1394.97	-632.88
Num. obs.	1758	1758	1758	1758
Num. countries	24	24	24	24
Num. groups: Regions.	293	293	293	293
Timeframe 2007 – 2012 (All Models)				

***p < 0.001, **p < 0.01, *p < 0.05, ^p < 0.1. Standard errors in parentheses.

Table 4.8: All regional new business entries and policy effects.

	All_OECD_EPS	All_OECD_Mkt
	Model 7a	**Model 7b**
Environmental_Knowledge	0.01	0.01
	(0.01)	(0.01)
EPS_Aggregate	-0.01	
	(0.05)	
Market_EPS		0.08*
		(0.03)
Non_Market_EPS		-0.13**
		(0.05)
Start_Up_Funding	-0.00	-0.00
	(0.01)	(0.01)
GDP_Capita	-0.20^	-0.19^
	(0.11)	(0.11)
Research_Institutes	0.47***	0.47***
	(0.04)	(0.04)
R&D % of GDP	-1.12***	-1.06***
	(0.13)	(0.13)
Ren Energy % of Tot. Energy	0.20***	0.17***
	(0.04)	(0.04)
Ren_Industry_Tilt	0.10	0.16
	(0.13)	(0.13)
	(0.01)	(0.01)
(Intercept)	9.90***	9.87***
	(1.12)	(1.11)
AIC	18612.50	18602.28
BIC	18692.24	18687.00
Log Likelihood	-9290.25	-9284.14
Num. obs.	1079	1079
Num. countries	14	14
Num. groups: Regions.	180	180
Timeframe 2008 - 2013		

***p < 0.001, **p < 0.01, *p < 0.05, ^p < 0.1

Standard errors in parentheses.

Table 4.9: Regional cluster robust standard errors for main models.

	Aggregate Country Policy Stringency Effects				Market vs. Non-Market Policy Effects				Individual Policy Instrument Effects			
	All	**Gray**	**Green**	**Brown**	**All**	**Gray**	**Green**	**Brown**	**All**	**Gray**	**Green**	**Brown**
	Model 3a	**Model 3b**	**Model 3c**	**Model 3d**	**Model 4a**	**Model 4b**	**Model 4c**	**Model 4d**	**Model 5a**	**Model 5b**	**Model 5c**	**Model 5d**
EPS_Aggregate	-0.32***	-0.31**	-0.42^	-0.86**								
	(0.10)	(0.10)	(0.22)	(0.31)								
Market_EPS					-0.16^	-0.12	-0.33*	-1.02***				
					(0.09)	(0.09)	(0.15)	(0.16)				
Non_Market_EPS					-0.14*	-0.16**	-0.08	0.22				
					(0.06)	(0.06)	(0.18)	(0.28)				
Market_Taxes									0.10	0.14^	0.12	-1.07***
									(0.07)	(0.07)	(0.15)	(0.18)
Market_Trading_Schemes									-0.04	-0.03	-0.02	-0.46**
									(0.04)	(0.04)	(0.11)	(0.14)
Market_FIT									-0.07^	-0.06^	-0.16*	-0.18^
									(0.03)	(0.03)	(0.07)	(0.10)
Market_DRS									0.10	0.10	-0.15	-0.38
									(0.09)	(0.09)	(0.21)	(0.34)
Non_Market_Standards									-0.06	-0.07	0.10	0.12
									(0.05)	(0.05)	(0.16)	(0.20)
Non_Market_RD_Subsidies									-0.07	-0.06	-0.17	-0.19
									(0.04)	(0.04)	(0.14)	(0.21)
Environmental_Knowledge	0.04^	0.04^	0.17**	-0.01	0.04^	0.04^	0.18**	0.02	0.04^	0.04	0.18**	-0.00
	(0.02)	(0.02)	(0.06)	(0.07)	(0.02)	(0.02)	(0.06)	(0.07)	(0.02)	(0.02)	(0.06)	(0.07)
Start_Up_Funding.	0.04***	0.04***	0.15***	0.14***	0.04***	0.04***	0.15***	0.15***	0.04***	0.04***	0.15***	0.15***
	(0.01)	(0.01)	(0.03)	(0.04)	(0.01)	(0.01)	(0.03)	(0.04)	(0.01)	(0.01)	(0.03)	(0.04)
GDP_Capita	0.54**	0.60**	1.23***	0.90*	0.54**	0.60**	1.21***	0.90**	0.51**	0.57**	1.24***	0.93**
	(0.19)	(0.19)	(0.30)	(0.38)	(0.19)	(0.19)	(0.30)	(0.35)	(0.19)	(0.19)	(0.30)	(0.36)
Research_Institutes	0.80***	0.81***	0.56***	0.75***	0.81***	0.81***	0.56***	0.73***	0.77***	0.77***	0.55***	0.79***
	(0.09)	(0.09)	(0.10)	(0.13)	(0.09)	(0.09)	(0.10)	(0.13)	(0.09)	(0.09)	(0.10)	(0.13)
R&D % of GDP	1.08***	0.94***	0.39	1.55**	1.02***	0.94***	0.28	0.86^	1.09***	0.98***	0.40	1.31**
	(0.24)	(0.24)	(0.30)	(0.48)	(0.23)	(0.23)	(0.31)	(0.44)	(0.23)	(0.23)	(0.32)	(0.46)
Ren Energy % of Tot. Energy	-0.09	-0.11	-0.19	0.07	-0.08	-0.11	-0.18	0.05	-0.10	-0.14	-0.15	0.13
	(0.11)	(0.11)	(0.13)	(0.20)	(0.10)	(0.10)	(0.13)	(0.17)	(0.10)	(0.10)	(0.13)	(0.17)
Ren_Industry_Tilt	0.10	0.14	0.18	-2.71**	0.07	0.13	0.11	-3.25***	0.08	0.15	0.18	-3.21***
	(0.22)	(0.23)	(0.34)	(0.85)	(0.22)	(0.22)	(0.34)	(0.96)	(0.22)	(0.22)	(0.33)	(0.91)
(Intercept)	-8.78***	-9.33***	-17.58***	-16.62***	-8.80***	-9.30***	-17.41***	-16.08***	-8.55***	-9.08***	-18.01***	-16.16***
	(1.77)	(1.74)	(2.88)	(3.74)	(1.78)	(1.75)	(2.86)	(3.42)	(1.72)	(1.70)	(2.91)	(3.47)
AIC	16592.92	16369.23	4984.854	2562.146	16599.74	16376.96	4984.905	2542.46	16596.71	16369.25	4989.366	2537.1
Log Likelihood	-8273.458	-8161.616	-2469.427	-1258.073	-8275.87	-8164.479	-2468.453	-1247.23	-8270.357	-8156.63	-2466.68	-1240.549
Num. obs.	3809	3809	3809	3809	3809	3809	3809	3809	3809	3809	3809	3809

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$, $^{\wedge}p < 0.1$. Cluster robust standard errors in parentheses.

4.7 Implications and conclusions

Our study contributes to the rising field of environmental entrepreneurship by drawing from the literatures on knowledge spillovers, environmental policy and innovation. Our findings unveil relationships between environmental policy, new environmental knowledge and high-growth start-up rates which has been an under-researched area in the literature. We highlight how the ripple effects of environmental policy may reach entrepreneurs and how it may have unintended consequences in a high-growth business segment.

The implication for effective policy design is that while environmental stringency of policies may be a necessary condition for the transition to a low carbon economy, it is not sufficient in motivating entrepreneurial action. These policies should also be adjusted to suit a national or regional entrepreneurship ecosystem if the policymaker view is that entrepreneurs are important in delivering the low carbon transition.

The lessons for entrepreneurs are also manifold. First, aspiring green entrepreneurs may enhance their likelihood of founding promising start-ups by participating in knowledge networks that have deep expertise in environmental management. Entrepreneurs who may not have environmental goals at all can also benefit by understanding the benefits of eco-efficiency on their business models. Last but not least, entrepreneurs may enhance their opportunities by participating in what Dean and McMullen (2007) call political entrepreneurship, or in other words, taking action in altering the nature of government policies. These policies need not be more environmentally stringent, as we have seen, but perhaps better matched with the country's or region's entrepreneurship policy.

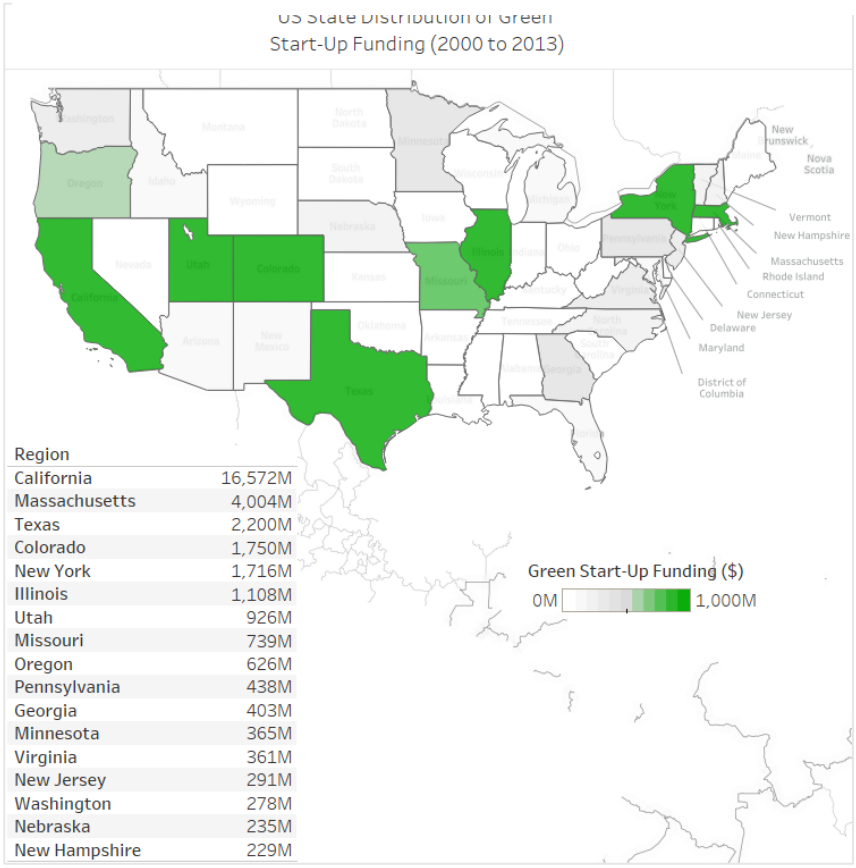
The issue at stake goes beyond green entrepreneurship. The stabilisation of global warming under any warming target requires the achievement of a net-zero emissions

economy (Matthews and Caldeira, 2008). Pfeiffer et al. (2018) show that this is highly unlikely to be achieved for the Paris Agreement 1.5°C – 2°C warming targets, given that planned energy infrastructure pipeline is likely to emit as much carbon as the present infrastructure portfolio. In the context in which incumbent structures and governments make only inadequate incremental steps towards fighting climate change, creating and finding the right conditions for green entrepreneurship to flourish is even more important.

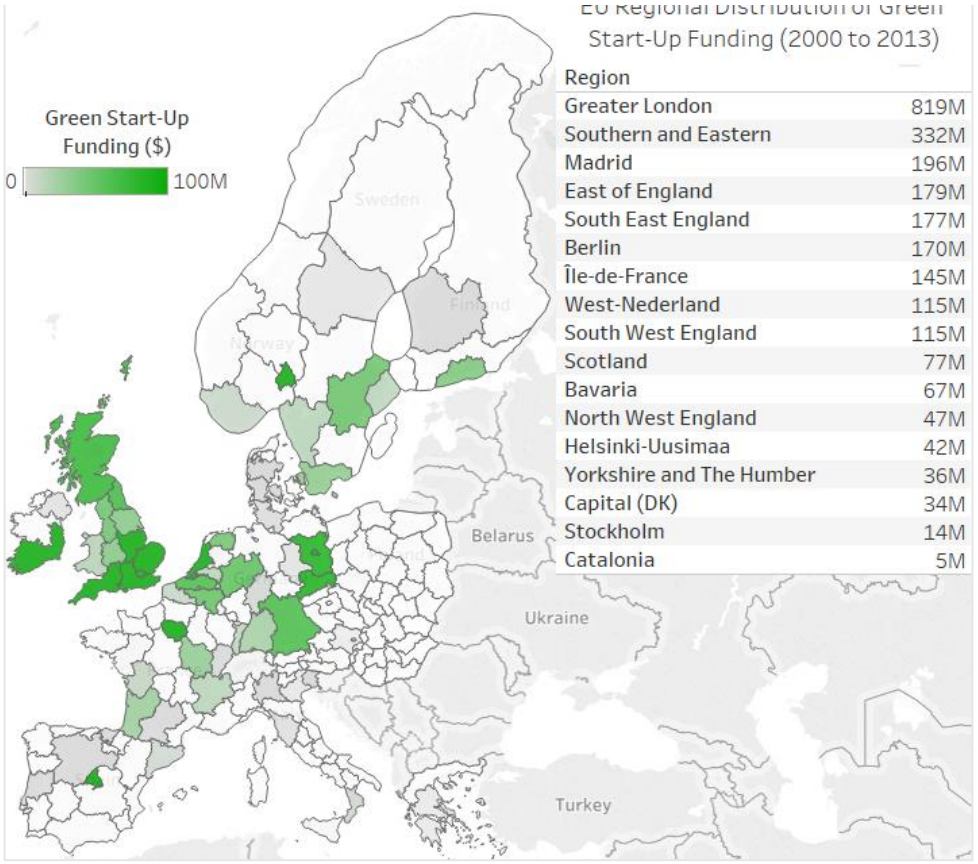
Our study has some limitations. While we manage to provide evidence at the granular policy instrument level, and how it affects new rates of entrepreneurship, we are unable to distinguish between the relative coherence, credibility or comprehensiveness of the policy mix at the country level which ultimately influence the environmental and economic outcomes of the policy (Rogge and Reichardt, 2016). Furthermore, policy instruments interact with each other and may enhance or diminish the overall strength of a policy regime. Further research would need to be conducted to explore these aspects. Another limitation has to do with the dataset which allows us to study environmental knowledge and policy effects on entry of high-growth start-ups only. Seeking to answer questions, such as does environmental policy affect the revenue growth of start-ups or do start-ups meaningfully contribute to the reduction of environmental degradation can provide complementary views to our research angle. Finally, the paper cannot tackle in full detail the different impacts of policy and knowledge on the entire entrepreneurship ecosystem, but rather focuses on high-growth entrepreneurs who are likely to receive investment and expand beyond the SME status. We only provide a preliminary analysis as a robustness test on a limited country set and timeframe and hence, would welcome further research on the topic.

Chapter 4 Appendices

Appendix A.4.1: US and European distribution of green start-up funding (2000 -2013).



Region	
California	16,572M
Massachusetts	4,004M
Texas	2,200M
Colorado	1,750M
New York	1,716M
Illinois	1,108M
Utah	926M
Missouri	739M
Oregon	626M
Pennsylvania	438M
Georgia	403M
Minnesota	365M
Virginia	361M
New Jersey	291M
Washington	278M
Nebraska	235M
New Hampshire	229M



Region	
Greater London	819M
Southern and Eastern	332M
Madrid	196M
East of England	179M
South East England	177M
Berlin	170M
Île-de-France	145M
West-Nederland	115M
South West England	115M
Scotland	77M
Bavaria	67M
North West England	47M
Helsinki-Uusimaa	42M
Yorkshire and The Humber	36M
Capital (DK)	34M
Stockholm	14M
Catalonia	5M

Appendix A.4.2: Correlation Matrix

Variables	Mean	St. dev.	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
[1] Green	0.86	3.91									
[2] Gray	27.27	128.92	0.89***								
[3] Brown	0.25	1.24	0.42***	0.40***							
[4] All Start-Ups	28.39	132.93	0.90***	1.00***	0.41***						
[5] Environmental_Knowledge	78.85	280.30	0.32***	0.32***	0.24***	0.32***					
[6] Start_Up_Funding($m)	97.69	834.12	0.50***	0.50***	0.37***	0.50***	0.65***				
[7] EPS_Aggregate	2.09	0.87	0.07***	0.08***	0.02	0.08***	0.36***	0.23***			
[8] Market_EPS	1.47	0.86	0.02	0.03	-0.02	0.03	0.25***	0.12***	0.89***		
[9] Market_Taxes	1.6	0.75	0.00	-0.02	0.00	-0.02	0.18***	0.00	0.43***	0.55***	
[10] Market_Trading_Schemes	1.10	1.22	0.08***	0.09***	0.01	0.09***	0.27***	0.26***	0.68***	0.61***	0.23***
[11] Market_FIT	1.72	1.94	-0.01	0.01	-0.03	0.01	0.11***	0.03*	0.65***	0.77***	0.10***
[12] Market_DRS	0.54	0.49	0.12***	0.11***	0.11***	0.11***	0.29***	0.26***	0.28***	0.13***	0.29***
[13] Non_Market_EPS	2.71	1.10	0.10***	0.11***	0.06***	0.11***	0.40***	0.29***	0.93***	0.65***	0.27***
[14] Non_Market_Standards	3.35	1.47	0.10***	0.10***	0.05**	0.11***	0.31***	0.28***	0.88***	0.66***	0.21***
[15] Non_Market_RD_Subsidies	2.06	1.14	0.06***	0.08***	0.04**	0.07***	0.38***	0.20***	0.65***	0.38***	0.24***
[16] Regional_GDP_Capita ($)	33862	15948	0.20***	0.20***	0.17***	0.20***	0.59***	0.47***	0.43***	0.33***	0.29***
[17] Research Institutes	128.64	221.23	0.33***	0.33***	0.27***	0.33***	0.76***	0.62***	0.26***	0.20***	0.28***
[18] Ren_Industry_Tilt	0.2	0.33	-0.06***	-0.06***	-0.08***	-0.06***	-0.06***	-0.12***	0.14***	0.04**	-0.08***
[19] R&D as % of GDP	0.95	0.35	0.16***	0.15***	0.13***	0.15***	0.64***	0.43***	0.49***	0.32***	0.32***
[20] Ren Energy % of Tot. Energy	2.1	0.61	-0.09***	-0.08***	-0.04*	-0.09***	-0.16***	-0.17***	0.19***	0.06***	-0.07***

Variables	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]
[11] Market_FIT	0.17***									
[12] Market_DRS	0.12***	-0.06***								
[13] Non_Market_EPS	0.63***	0.44***	0.37***							
[14] Non_Market_Standards	0.65***	0.48***	0.28***	0.91***						
[15] Non_Market_RD_Subsidies	0.38***	0.21***	0.36***	0.77***	0.44***					
[16] Regional_GDP_Capita ($)	0.25***	0.20***	0.35***	0.44***	0.34***	0.41***				
[17] Research Institutes	0.21***	0.01	0.36***	0.28***	0.23***	0.22***	0.52***			
[18] Ren_Industry_Tilt	0.02	0.08***	0.08***	0.17***	0.14***	0.16***	-0.06***	-0.19***		
[19] R&D as % of GDP	0.25***	0.16***	0.50***	0.54***	0.39***	0.56***	0.69***	0.53***	0.04*	
[20] Ren Energy % of Tot. Energy	0.08***	0.08***	0.17***	0.26***	0.19***	0.28***	0.01	-0.26***	0.34***	0.01

Note: The matrix is based on region-year observations between 2001 and 2013. Environmental policy stringency indices appear in the same regression only if they are at the same level of granularity (e.g. variables 8 and 13, or variables 9,10,11,12,14 and 15).

5 Developing an Evidence Base for Assessing Natural Capital Risks and Dependencies in Lending to Australian Wheat Farms

5.1 Introduction

Agriculture is a small but important part of the Australian economy, accounting for 7% (by value) of total exports in 2014-15 (ABS, 2016a), and contributing as much as 12% of Australia's GDP, when including the value of associated pre- and post-farm production activities (NFF, 2012). Farmers own or manage 61% of Australia's land (NFF, 2012) and therefore play a key role in managing Australia's stocks of natural capital, or "those elements of nature which either directly provide benefits or underpin human wellbeing" (Natural Capital Committee, 2013, p. 11).

Farmers all over the world are highly dependent on environmental factors such as rainfall, temperature and climate, as well as natural capital stocks such as energy, mineral and water resources, productive soils and ecosystems. Australia's aridity (70% of mainland Australia receives less than 500mm of rain per year – Geoscience Australia 2016) and generally poor soils means that Australian agriculture is particularly vulnerable to variability and extreme conditions. For example, widespread drought in 2002-03 led to a 41% reduction in agricultural income, reducing Australia's GDP by around 1% in that year (Lu and Hedley, 2004).

99% of the 134,000 farm businesses operating in Australia in 2012 were family owned (NFF, 2012), with on average 85% of business equity being held by the operator and close relatives or business partners (ABARES, 2016). The remaining 15% takes the form of debt, including short-term unsecured debt such as credit cards; equipment supplier finance; and formal secured loans, usually from one of the small number of Australian banks with extensive rural networks. Through these loans, which are typically

used either to fund land or machinery purchases, or to provide working capital to bridge temporary income-cost mismatches, these banks are exposed to a range of natural capital and environmental risks and dependencies. The traditional process for assessing a farmer's credit risk, however, relies primary on historical financial data, which only indirectly and incompletely reflects these risks and dependencies.

In 2012, around 40 international financial institutions signed the Natural Capital Declaration (NCD), committing to integrate natural capital considerations into their financial products, and their accounting and reporting frameworks, by 2020.[15] A pilot study (Cojoianu et al., 2015) found that 42% of financial institutions claim to be already integrating natural capital risks in credit risk assessments. However, the evidence to date suggests that this is limited to large (over US$10 million) project finance deals and even larger corporate loans, and is virtually non-existent for smaller secured loans typical of the Australian agricultural sector. A key challenge for agriculture is the fact that the relevant risks and dependencies vary by sub-sector and in some cases by individual crop or animal production system, as well as by geography. Other difficulties include lack of awareness around natural capital issues, the vagueness of regulatory requirements around natural capital issues, the challenge of relating long-term issues to short-term materiality, and most importantly, lack of standardized industry- and geography-specific methodologies and robust information for the quantification of natural capital risks (Cojoianu et al., 2015). Our paper therefore aims to help address these challenges by developing an evidence base to support natural capital credit risk assessment for a single sub-sector of Australian agriculture – wheat farming, which contributed over A$7 billion

[15] http://www.naturalcapitalfinancealliance.org/about-the-natural-capital-declaration/ (accessed 26 October 2016).

or 13% of Australia's total value of agricultural production in 2015, second only to cattle grazing (ABS, 2016b).

The paper is structured as follows. In section 2, we review the literature on environmental credit risk assessment. Section 3 outlines our methodology for identifying key environmental and natural capital risks and dependencies, and section 4 sets out our findings for the Australian wheat sector, explaining why each risk is material, how it can be mitigated, and how a bank could assess and monitor the risk. Finally, section 5 discusses the overall findings that emerged from this analysis.

5.2 Environmental credit risk assessment

The literature on sustainability in the banking sector can be divided into two broad groups (Zeidan et al., 2015): one dealing with external practices (which include banks' communications with shareholders and stakeholders around sustainability issues) and the other with internal practices (which include how sustainability issues are incorporated into risk management models and lending or investment decisions). Our paper contributes to the latter.

Within this strand of the literature there are two main areas of focus. The first considers how environmental performance influences the perceived credit risk and cost of debt of companies, with most studies finding that firms with better sustainability performance ratings experience a lower cost of debt, and vice versa (Bauer & Hann 2010; Nandy & Lodh 2012). Most studies focus on public companies in developed countries (although Weber, Hoque, and Ayub Islam (2015) provide evidence linking sustainability criteria to loan default probability in a developing country, while noting that sustainability criteria are not yet being used by lenders there), and on major risks such as hazardous chemicals, substantial emissions and climate change (Schneider 2011; Chava 2014). Most papers also focus on large-scale corporate loans and bond finance, rather

than smaller loans to privately held companies and SMEs, where data on sustainability as well as financial issues is much scarcer and opaque (Berger and Udell, 1998). There is, to the best of our knowledge, no peer-reviewed research demonstrating a clear link between environmental performance at this smaller scale, and the availability, terms or cost of bank loans. Nevertheless, from our discussions with Australian banking officials it appears that at least some banks are operating on the assumption that there is such a link:

> "I guess, you know, there's an assumption that we've made, that seems to be validated by numerous case studies, that our more productive agribusiness customers are those who manage their environmental resources better, and they seem to be one and the same thing." (Environmental finance professional, August 6, 2015).

The second area concerns the extent to which banks incorporate sustainability criteria in their lending decision-making. It is generally agreed that banks have been incorporating *some* environmental risks into their credit assessment processes, since the early 1990s (Weber, Fenchel, & Scholz 2008). This was originally driven by legislation, such as the Comprehensive Environmental Response, Compensation and Liability Act 1980 in the United States, which imposed remediation liabilities on the owners of contaminated sites. As a result, early environmental credit risk assessments tended to focus only on such specific liabilities, rather than providing a comprehensive framework for the assessment of all potentially material environmental (and social) risks, dependencies and opportunities. In the mid-2000s, Weber, Fenchel, & Scholz (2008) identified only four classes of environmental risk being considered by banks: contamination liabilities; impacts of mandatory environmental regulations; changes in buyer/consumer attitudes; and reputational risk due to being associated with projects seen as environmentally or socially damaging by stakeholders. Furthermore, they found that most attention was given to environmental issues in the rating (or risk identification) phase of the credit management process, least in the costing (or risk evaluation) phase and an intermediate level in the monitoring (or risk controlling) phases.

A recent survey of 36 financial institutions and 26 financial research providers undertaken for the NCD (Cojoianu et al., 2015) found that although 42% of respondents claim to consider natural capital risks in their credit risk assessment, there is no evidence that this is done systematically. Lenders cited numerous difficulties in assessing natural capital risks including the lack of suitable contextual methodologies, data, budgets and capacity. Currently, only project finance transactions and related services can be benchmarked to an international standard of environmental and social due diligence: the Equator Principles, which are applied only to projects over US$10 million, or US$100 million for corporate loans.

The aforementioned body of research on sustainability performance and perceived credit risk of borrowers goes some way toward explaining why banks might seek to incorporate environmental risks and dependencies in their credit assessment processes. As Weber, Hoque, and Ayub Islam (2015, 3) observe, "The rationale for using sustainability indicators for predicting credit risks is based on the idea that good sustainability performance mitigates risks arising through environmental and social impacts as well as through and stakeholder pressure and regulation." However, while high-level sustainability indicators may be available for larger companies, usually based on research providers' analysis of annual and sustainability reports, they are typically not applicable to smaller-scale loans such as those typical in the Australian agricultural sector.

Very little research has been published on the incorporation of environmental risks and dependencies into credit assessment for smaller-scale loans in any sector, or for any scale of loans in agriculture in particular. A search across all academic databases subscribed to by the University of Oxford using the keywords 'environmental', 'credit', 'risk' and 'agriculture' yielded only 80 results, only a few of which were found to be

relevant. For example, Georgopoulou et al. (2015) develop a framework to assess the risk of climate change to lending across several Greek industries, including wheat farming, using the loan portfolio of a Greek bank as a case study. The authors use climate and agronomic modelling to make the case for materiality of climate change to the agriculture sector and conclude that the physical risks from climate change to Greek crop farms are between 7.4-12.4% of their annual turnover. However, they do not provide an evidence base for the assessment of more granular risk factors (e.g. rainfall availability), but rather rely on a generic crop yield simulation model. The emphasis is on calculation of portfolio-level exposure to systemic risks, as opposed to individual loan assessment. Similarly, Do et al. (2016) find evidence that banks are considering drought risk at a systemic level, increasing loan interest rates to large agricultural enterprises by up to 6 basis points for every step increase in regional drought level in the 12 months prior to loan origination. Zeidan et al. (2015) propose a sustainability credit score system for the sugar industry in Brazil, based on six dimensions: economic growth, environmental protection, social progress, socio-economic development, eco-efficiency and socio-environmental development. Whilst taking a higher-level sustainability focus, this study is the most complementary to our own in terms providing a basis for the evaluation of such risks for a specific sector and country.

In summary, there is an almost complete absence in the literature of detailed assessments of how environmental and natural capital risks can be identified and included in the credit risk assessment process for smaller-scale (e.g. US$0.5-2 million) bank loans. This is true across industries, and for agriculture in particular. Our paper complements the top-down approach taken by Zeidan et al. (2015) by developing a bottom-up, robust evidence base on why and how different natural capital risks and dependencies are likely to affect the financial performance of wheat farms in Australia,

how these risks can be managed, and how the resultant managed risk can be assessed by a lender.

5.3 Methodology

We followed a multi-stage approach to identifying, prioritizing and researching the natural capital risks and dependencies applicable to Australian wheat farm lending, from a lender's perspective. First, we searched the publicly available environmental risk methodologies of 66 financial research providers and consultants identified by Cojoianu et al. (2015) for environmental risk factors specifically relevant to the agricultural sector. As we found that coverage of agriculture was limited to just nine research providers, we also conducted a desk review of 34 publications from financial institutions related to environmental risks, published between 2006 and 2016, to identify high level environmental risk factors which were considered to be material across a broad range of industries. Those most applicable to agriculture are listed in **Table 5.1** below.

The next step was to determine which of these risks were of most importance for wheat farming, in the Australian context in particular. To do this we triangulated evidence from three different sources: a review of 39 relevant academic papers shortlisted from a set of 974 papers containing the keywords 'wheat', 'Australia' and 'yield' in the Scopus database; a review of online publications from Australian industry-specific bodies (such as the Grains Research and Development Corporation, GRDC) and relevant government agencies; and a set of four interviews with Australian agribusiness professionals, credit managers and environmental finance professionals. Typically, industry body publications proved the most useful in demonstrating the materiality of specific environmental risks to the wheat industry, given their focus and access to information specific to the Australian context.

A risk was considered material if it was clearly capable of being a significant determinant of either yields, prices or costs, either in the short- or long-term. It was not practicable to set quantitative thresholds for significance, but where possible we have provided quantitative evidence in support of our judgment. We consider historical average conditions to be the baseline: a risk is therefore only significant if it results in a deviation (in a negative direction) from this baseline, either in the short- or long-term. It should be noted that risk is the product of the probability of occurrence and the magnitude of impact, and it is therefore appropriate to include some factors which are low impact but high probability, and vice versa. In addition, some factors have been included on the basis of externalities which are currently not fully priced, but which may become more appropriately priced in the medium to long term.

Finally, to keep this paper concise, we excluded weather, climate, energy and air emissions risks, as these are already relatively well understood. The results of these steps are summarized in **Table 5.1** below. Factors relevant to wheat farming are highlighted in gray, with light gray indicating the factors that are considered material, but not included in the following discussion.

Table 5.1: Agriculture – environmental and natural capital risk factors.

Thematic Area	Risk Factor	Sub-Risk Factor
Water	Water Availability	Growing Season Average Rainfall (Lower Quantity or Increased Variability
		Excessive Rainfall
	Water Use Efficiency	Crop Water Use Efficiency
		Pasture Water Use Efficiency
		Animal Stock Watering Efficiency
		Farm Water Use Efficiency
	Water Rights	Quantity
		Price
	Irrigation Technology Failure	
	Water Quality	Salinity Management
		Water Contamination
		Water Acidity
Weather and Climate	Heat Stress	
	Frost Damage	

	Extreme Weather Events	
Land Use and Pollution	Fertiliser Use	Quantity
		Price
		Run-Off
		Appropriate Application
	Soil Organic Carbon	
	Soil Erosion	Water Erosion
		Wind Erosion
	Soil Acidification	
	Soil Salinity	
	Soil Compaction	
	Organic Contaminants	
	Heavy Metals	
	Waste Management	
Biodiversity and Ecosystems	GMO Contamination	
	Pests and Diseases	
	Weeds	
	Biodiversity	
	Livestock Health/Animal Welfare	
	Pasture Cover and Composition	
Energy Use	On-Farm Energy Use	
	Fertiliser Production and Transport Energy Use	
Air Emissions	Carbon Dioxide	Energy Use Emissions
		Fertiliser Production and Transport Energy Emissions
		Direct Land Use Change Emissions
	Methane	Enteric Fermentation Emissions
		Manure Management Emissions
	Nitrous Oxide	Fertiliser Application Emissions
	F-gases (Hydrofluorocarbons, Perfluorocarbons and Sulfur Hexafluoride)	

The same sources of evidence were then used to explore each of these risks in further detail. In the following section, for each key risk, we discuss why it is material, what mitigation options are available, and what information a lender would require to assess and monitor these risks, either quantitatively or qualitatively. The key risks identified for wheat can, for ease of discussion, be grouped into the following headings: water; fertiliser use; soil health; pests, diseases and weeds, and biodiversity.

Hoepner et al. (2014) point out that banks can adopt two different approaches to assess the credit-worthiness of a borrower. The first is the traditional approach to credit risk assessments or ‘transaction-based banking’, which is based on quantitative and

easily verifiable information, predominantly financial metrics. The second is 'relationship banking', in which lending decisions are based on intangible factors which are harder to quantify, often collected manually and difficult to verify (e.g. managerial competence). The authors highlight a growing body of literature showing that the use of intangible information in tandem with financial metrics can lead to better credit risk assessments than those based only on financial factors. Hence we have considered both quantitative and qualitative information that could contribute to assessing each risk.

5.4 Natural capital risks and dependencies in Australian wheat farming

Most of Australia's grain production is located on a narrow belt of land (in the east, south east and south west of the country), known as the Wheatbelt or Grainbelt, which benefits from a temperate climate, sufficient rainfall (on average 300-600mm/year) and relatively fertile soils (Land Commodities, 2012). At 46 million hectares, the Wheatbelt comprises 6% of Australia's total land area (Land Commodities, 2012). Despite the name, farmers in the Wheatbelt also raise livestock and grow other crops in addition to wheat. In 2014-15, wheat was grown on about 57% (13.8 million ha) of total Wheatbelt farmland (24.3 million ha) (Farrell, 2015).

The majority of Australia's grain, including around 90% of wheat, is grown in a single winter growing season, with precise sowing and harvesting periods varying by region (Land Commodities, 2012). There is minimal water available for irrigation across the Wheatbelt, hence almost all grain in Australia is produced under a dryland cropping system (i.e. crops are rain-fed, not irrigated). Rainwater availability and efficiency of use is therefore a key natural capital risk/dependency for Australian wheat farming.

5.4.1 Water

Overview

The level of rainfall is the biggest predictor of agricultural productivity in a given year, and long-term averages are a key determinant of land prices (Land Commodities, 2012). Rainwater availability for any crop is a function of four inter-related dimensions (Land Commodities, 2012):

- **Quantity** (total annual average rainfall);
- **Timing** (in particular, the amount received during the growing season, and the amount received in excessive downpours which can cause damage during the growing season or at harvest time);
- **Reliability** (the variability of both quantity and timing from year to year); and
- **Water use efficiency** (the proportion of rainfall which becomes available to the crop itself, which itself is a function of various factors including soil characteristics, drainage, topography, timing of rainfall events, climatic conditions after rainfall, nitrogen supply, weed cover and crop characteristics).

In a relatively small study (based on rainfall data from six weather stations in New South Wales over six years) CelsiusPro AG (2010) found a linear relationship between wheat yields and cumulative rainfall during the late growing season (1st August to 31st September), with rainfall over this period explaining 90% of the annual variation in wheat yield. This suggests that every millimeter less rainfall in the late growing season would result in a decrease in yield of 0.0188 t/ha (compared with average yields of around 1.5 t/ha). Assuming an average farm-gate price of A$250-300/t, this would translate into a decrease in earnings of A$4.70-5.64/ha/mm. This is significant in the context of typical profit margins of 10-20% or roughly A$37.50-90.00/ha based on the

same yield and price assumptions.[16] While further work is required to establish whether these implications hold for other regions and time periods, it does suggest that the **quantity of rainfall during the late growing season** is a critical component of water risk for wheat.

Risk mitigation

Farmers can mitigate the impacts of rainfall variability in several ways. Huda (1994) concludes that yields can be protected by reducing the area sown when rainfall is low (less than 40mm) in the early growing season (1st April -15th June) and increasing the area sown when rainfall is high (greater than 100mm). Timing is also important: farmers should decrease planting when the opening of the rainy season is delayed, and increase planting when the opening is early. Choosing to grow a longer-duration wheat cultivar in early rainfall years, or increasing sheep stocking as an alternative to wheat during low rainfall years is another option given accurate and early forecasting capabilities of growing season rainfall. A variety of actions can be taken to improve crop water use efficiency, for example by increasing the depth of rooting (Turner, 2004). However, this strategy is most effective on sandy soils in high-rainfall zones where nitrogen may leach into the root zone, with neutral and sometimes even negative effects in clay soils which experience limited wetting to root depth (Smith and Harris, 1981).

Lender information requirements

In the short term, lenders providing finance to wheat farmers can assess likely rainfall quantity, timing and variability according to location, by comparison with historical rainfall data. In Australia, Bureau of Meteorology data is likely to be sufficient, but could be supplemented with farm-specific rainfall data, particularly for remote areas. In addition,

[16] Own analysis. Indicative prices and profit margins from personal communication, Agribusiness finance manager, August 12, 2016.

lenders could qualitatively determine whether the farmer has the necessary knowledge and track record to deal with variable rainfall patterns and to employ appropriate risk mitigation measures as described above and in **Table 5.2**. In the longer term, shifting rainfall patterns could change the risk profile of wheat farms. Assessing this risk requires inputs from state-of-the-art climatic models producing decadal and regional projections.

Table 5.2: Water risks, information needs and data sources.

Risk Factor	Timeframe	Scale	Information Need	Data Sources
Growing Season Rainfall	Short term	Region to farm	Region- or farm-specific critical growing season dates	Bureau of Meteorology or farm-specific rainfall datasets combined with regional- or farm-specific yield records
	Short term	Region to farm	Region-specific historical average growing season rainfall and variability (e.g. over 10 years)	Bureau of Meteorology or farm-specific rainfall datasets
	Short term	Farm	Farmer's ability to predict and deal with variability	Farmer questionnaire
	Long term	Region	Projected changes in growing season rainfall patterns	Regional outputs from long-term climatic models
Harvesting Season Excessive Rainfall	Short term	Region to farm	Farm exposure to excessive rainfall during growing season or harvesting season	Farmer questionnaire on historical crop damage in growing or harvesting season. Bureau of Meteorology or farm-specific rainfall datasets.
Crop Water Use Efficiency	Short term	Farm	Recent historical average water use efficiency, compared with the same data for similar farms	Farmer yield data and Bureau of Meteorology or farm-specific rainfall datasets
	Short term	Farm	Farmer's ability to improve water use efficiency	Farmer questionnaire

5.4.2 Fertiliser use

Overview

Fertiliser use has significant environmental impacts in several ways: it represents consumption of various input natural resources and energy; it results in GHG emissions in both production and consumption; and it has the potential to both positively and negatively impact other natural resources, notably soil, water and biodiversity. It is also economically very important for farmers: fertiliser use is estimated to add $12.7 billion in increased productivity to the Australian agriculture sector (Ryan, 2010). The purchase of fertiliser is generally the largest single variable cost for grain producers, typically amounting to 15-20% of annual cash costs (IPNI, 2013). Thus nutrient use efficiency for

nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) is an indicator of more general resource use efficiency (IPNI, 2014a).

Having the right amount of nutrients in the soil when the crop needs it most is crucial for both yield optimisation and long-term soil health. While fertiliser is a major contributor to crop yield and health, mismanaging its application can result in significant risks for both the financial wellbeing of the farm and the environment. Key fertiliser related risks include:

- Rising fertiliser input quantity and cost;
- Energy use and associated GHG emissions across the supply chain;
- Crop over- or under-fertilisation resulting in soil degradation; and
- Off-field run-off into adjacent watercourses, water tables or land.

Farmers have an incentive to manage fertiliser efficiently to reduce costs, but there may be trade-offs between up-front costs of efficiency investments (such as smarter fertiliser application systems) and the longer-term benefits of efficiency improvements, as well as between positive short-term yield improvements and negative longer-term soil, water or GHG impacts. Two complementary indicators are particularly relevant for nutrient use efficiency. These are (IPNI, 2014b):

- Partial Nutrient Balance (PNB) which is measured as kg nutrient removed from soil / kg applied and can provide an insight into whether soil is under- or over-fertilised; and
- Partial Factor Productivity (PFP), or the crop yield per unit of fertiliser applied (kg yield / kg nutrient applied).

Benchmarks are available for these indicators: for example, IPNI (2016) recommend that, for cereal crops harvested for grain, PNB (nitrogen) should be in the range of 0.1-0.9 kg/kg with a PNB >1.0 kg/kg implying that the soil is being ‘mined’ for

short-term productivity gain at the expense of longer-term degradation, while PFP (nitrogen) should be 40-80 kg/kg. Similar benchmarks can be established for phosphorus, potassium and sulphur, and a lender could establish their own benchmarks across a portfolio of similar farms. However, differences in soil type, crop variety, micro-climate and other factors may make it difficult to distinguish between best and worst performers: for example, Mahjourimajd et al. (2016) find that different wheat genotypes have a significantly different PFP in low rainfall environments in Australia.

Risk mitigation

While rising fertiliser input costs, production energy use and associated GHG emissions are outside the control of the farmer, fertiliser application rates, timing and location can all be influenced, thereby affecting the total cost of fertiliser to the farmer, consumption-phase GHG emissions, and impacts on soil and water.

Lender information requirements

Lending institutions can monitor both the risk factors which are outside the farmer's control (fertiliser costs, fertiliser production energy use and GHG emissions) and those which are within the farmer's influence such as soil nutrient balance, fertiliser productivity, timing and placement.

Table 5.3: Fertiliser use risks, information needs and data sources.

Risk Factor	Timeframe	Scale	Information Need	Data Sources
Fertiliser quantity and cost	Short term	Farm	Fertiliser quantity (absolute or kg/ha) and percentage of total annual farm cash costs. Farmer's ability to balance fertiliser purchasing decisions with weather dependent fertiliser requirements	Farmer questionnaire
	Long term	National	Predicted fertiliser price trends	Market analysts
Fertiliser production and transport energy use and GHG emissions	Short and long term	National	Energy and GHG emissions per kg fertiliser	Life-cycle assessment studies, fertiliser manufacturer disclosure and/or farmer questionnaire
Appropriate application of fertiliser	Short term	Farm	Farmer's ability to optimise fertiliser application	Farmer and peer questionnaire (peer with similar rainfall profile)
	Long term	Farm	Impact of fertiliser application on soil quality (e.g. monitoring PNB)	Soil samples (for nutrient removal rate); farmer questionnaire (for fertiliser applied)
Fertiliser run-off	Short and long term	Farm and surrounding area	Adjacent water and soil contamination from fertiliser run-off	Farmer questionnaire; environmental regulator data

5.4.3 Soil health

Overview

Agricultural activity relies heavily on the underlying health of the soil. However, agricultural activity itself can undermine soil health through changes in nutrient balance and alkalinity, or through increased exposure to water and wind erosion, for example as a result of tillage, loss of soil surface cover and removal of crop residues. Soil health related risks translate directly into decreased agricultural productivity, long-term natural capital degradation and depreciation in land value.

Sbrocchi et al. (2015, 37) argue that soil condition indicators would ideally be a comprehensive "measure of the soil's capacity to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation". The multi-dimensional nature of soil health means that, in an ideal world, at least seven different indicators would be monitored: acidification, soil organic carbon, water erosion, wind erosion, salinity, nutrients, physical condition and biological condition. Physical and biological condition is very difficult to monitor at the extensive scales relevant to Australian wheat farming, and is therefore not considered further. In the remainder of this section we discuss the first five indicators, with nutrient balance being already considered in the section on fertiliser use.

Soil acidification is a slowly-occurring natural process which is accelerated by agriculture, mainly due to excessive use of ammonium-based fertilisers, and partly because the product removed (e.g. grains or other crops) is alkaline. Nitrogen in ammonium-based fertilisers is readily converted to nitrate and hydrogen ions in the soil. If the nitrate is in excess of what can be taken up by the plants it can leach away, causing

a build-up of hydrogen ions, or acidity, resulting in poor root growth and restricted access to water and nutrients.

It is estimated that more than 70% of surface soils and half of subsurface soils across the Wheatbelt are affected by soil acidity (Wheatbelt NRM, 2013), which results in up to A$500m/year in lost production.[17] The optimal pH range for wheat is around or above pH 5.5 in the topsoil and 4.8 in the subsurface – key thresholds below which root growth is impaired (Gazey & Andrew 2009).

Soil organic carbon (SOC), and the ability of soil to store it, is regarded as an important basis for soil fertility, and consequently, crop yields. It is also an important component of the global carbon cycle, with potential to provide either substantial additions or removals to atmospheric CO_2 levels, depending on how it is managed. Across Australia, the total stock of organic carbon in the top 30 cm of soil is estimated to be 19-32 GtC (Viscarra Rossel et al., 2014). In Western Australian soils under broadacre grain production, SOC is typically 0.8-2% of soil mass in surface soils (the top 10cm), or the equivalent of 8-20 tC/ha (Hoyle, 2016).

Increased soil carbon levels can benefit crop growth through processes such as improved nitrogen and water supply to crops. However, this is the case only at low fertiliser application rates (0-50kg N/ha), when the crop relies on mineral nitrogen from soil organic matter rather than nitrogen supplied by farmers (Palmer et al., 2015). At higher rates of fertiliser application, which is more typical of current farming practices, there was little or no productivity benefit from increased SOC.

Dryland **salinity** occurs when the concentration of soluble salts near the soil surface is sufficient to reduce plant growth. Dryland salinity develops when a supply of

[17] https://www.agric.wa.gov.au/news/media-releases/world-soil-day-wa-soil-acidity-research-boosts-yields-and-profitability (Accessed 27 October 2016)

water and a store of salt in the soil meets the ground surface, mainly due to clearing for agriculture and the replacement of deep-rooted perennial vegetation with shallower rooted annual crops. Up to 17 million hectares of mostly agricultural land in Australia is thought to be at risk of developing salinity problems by 2050 unless effective action is taken to mitigate this risk (ABS, 2013). Salinity is also thought to have caused a 50% decrease in the numbers of wetland bird species, and is threatening 450 plant species with extinction (ABS, 2013).

Water and wind erosion can impact wheat yields by removing fine fractions of soil which include clay, organic matter and soil nutrients, resulting in reduced capacity of the soil to retain water and nutrients. If the top 10 mm of soil are subjected to erosion, crop yields can be reduced by 25% (DAFWA, 2013).

Risk mitigation

Soil acidification risk can be mitigated by using acid-tolerant cultivars of wheat, in conjunction with liming to recover soil pH to target levels (Gazey and Davies, 2009). SOC loss can be slowed, or even reversed, by optimizing agricultural management through stubble retention, fertilisation and conservation tillage (Wang et al., 2013). The four major strategies available to address salinity are the planting of more salt-tolerant crops, the planting of trees, the fencing of land from grazing and the construction of earthworks such as drains (ABS, 2003). Finally, water erosion can be minimized through stubble retention and the construction of earthworks to reduce the velocity and volume of peak flows,[18] and wind erosion can be controlled by reducing wind-speed at ground level (e.g. by planting windbreaks) and minimising soil disturbance. Around 50-75% ground cover is required to minimise erosion, depending on soil type (DAFWA, 2013).

[18] https://www.agric.wa.gov.au/water-erosion/water-erosion-introduction (Accessed 1 December 2016)

Lender information requirements

Lending institutions would be primarily interested in the farmer's ability to manage soil health issues, and in monitoring long-term trends in the above indicators for evidence of soil health degradation.

Table 5.4: Soil health risks, information needs and data sources.

Risk Factor	Timeframe	Scale	Information Need	Data Sources
Soil acidification	Short term	Farm	Farmer's ability to monitor and manage soil acidification	Farmer questionnaire
	Long term	Farm	Change in soil pH over time	Soil samples
Soil organic carbon	Short term	Farm	Farmer's ability to monitor and manage SOC	Farmer questionnaire
	Long term	Farm	Change in SOC over time and estimated carbon dioxide equivalent emissions or removals	Soil samples plus published conversion factors
Soil salinity	Short term	Farm	Farmer's ability to monitor and manage salinity	Farmer questionnaire
	Long term	Farm	Change in salinity over time	APSoil database (baseline) plus on-going soil samples or electromagnetic mapping
Water and wind erosion	Short term	Farm	Farmer's ability to monitor and manage erosion	Farmer questionnaire
	Long term	Farm	Soil loss over time	Farmer observations (e.g. photos); erosion maps

5.4.4 Pests, diseases and weeds

Overview

Pests, diseases and weeds can be seen as ecosystem interactions that result in reduced crop health and yields if farmers do not take appropriate action to mitigate their impacts. They can also have significant impacts on other forms of natural capital such as biodiversity, soil or water quality. The economic losses associated with pests, diseases and weeds in the Wheatbelt are summarized in **Table 5.5**.

Table 5.5: Yearly economic loss related to pests, diseases and weeds in agriculture. Data sources: GRDC (2013) and Australian Government (2016).

	Pests	Diseases	Weeds
Economic loss	A$789m/year or A$60/ha	A$913m/year or A$76.64/ha	A$1.5bn/year (weed control) + A$2.5bn/year (lost agricultural production)

The risks to wheat crops from pests, diseases and weeds are material to not only short- and long-term crop health, but also to the surrounding environment and its ecosystems.

Risk mitigation

Management of pests and diseases is achieved by the use of resistant cultivars, paddock preparation and management, and application of pesticides (Murray and Brennan, 2009). Weed control relies on effective monitoring plus interventions such as winter cleaning of pastures or chemical fallowing.

Lender information requirements

Lenders would be interested in the historical frequency and severity of pests, diseases and weeds affecting a particular region or farm, the farmer's ability to monitor and mitigate those risks and projected changes in risk incidence over time.

Table 5.6: Pests, diseases and weeds risks, information needs and data sources.

Risk factor	Timeframe	Scale	Information Need	Data Sources
Pests and diseases	Short term	Farm to region	Frequency and severity of pests and diseases outbreaks, and farmer's ability to monitor and manage	Grain Research and Development Corporation (GRDC) reports and datasets and farmer questionnaire
	Long term	Farm to region and national	Projected changes in frequency of occurrence of pests and diseases outbreaks	GRDC reports and datasets
Weeds	Short term	Farm to region	Time and resources spent on weed management and farmer's ability to monitor and manage	Farmer questionnaire
	Long term	Farm to region and national	Projected changes in distribution of weeds	GRDC reports and datasets

5.4.5 Biodiversity

Overview

Australia's biodiversity is in decline, with more than 1,700 species and ecological communities known to be at risk.[19] The key threats to biodiversity include agricultural practices which lead to loss, degradation or fragmentation of habitats, changes to water

[19] http://www.environment.gov.au/biodiversity/threatened/species (accessed 23 March 2017).

flows and quality, altered fire regimes and the introduction of invasive pests, diseases and weeds.

Biodiversity has many different values. These include regulation of bee pollination, recreational/amenity values, and cultural/spiritual values among others. However, only some of these values are currently priced in some way (e.g. Australia's commercial fisheries are valued at $2.2 billion) (ABS, 2010). Threatened species and ecological communities are protected in Australia under the Environment Protection and Biodiversity Conservation Act 1999, which controls actions likely to cause significant impacts.

Risk mitigation

A variety of actions can be taken to avoid negative impacts and/or to positively enhance biodiversity. These include: mapping, conserving and regenerating remnant patches of native vegetation; creating buffers and setting land aside for biodiversity; creating corridors between areas of relatively undisturbed habitat; and controlling invasive species.

Lender information requirements

Lenders would be interested in understanding the baseline condition of biodiversity on the farm, the projected long-term trend for biodiversity in the area, and the farmer's ability to monitor and manage biodiversity. Whether the farm is in a biodiversity hotspot or close to the range of a threatened species could be indicators of high quality risk.

Table 5.7: Biodiversity risk - information needs and data sources.

Risk factor	Timeframe	Scale	Information Need	Data Sources
Biodiversity	Short term	Farm	Extent of remnant native vegetation (ha)	Farmer questionnaire
	Short term	Region	Quality of biodiversity	Biodiversity hotspots map; Atlas of Living Australia; region-specific studies
	Long term	Region	Projected changes in biodiversity	CSIRO and other research on climate change and other long-term impacts on biodiversity
	Short term	Farm	Farmer's ability to monitor and manage biodiversity	Farmer questionnaire

5.5 Conclusions

Developing a detailed, context-specific understanding of potential environmental risks and dependencies applicable to smaller-scale borrowers could not only help overcome the inevitable information asymmetry between borrower and lender (Akerlof, 1970), but also help identify and price risks that the borrower themselves may not be aware of. A bank's ability to demand information from its customers (Goss & Roberts 2011) and to analyse this across a portfolio in combination with other sources of information has the potential to detect systemic opportunities or risks in any area of business, and may be particularly applicable to sustainability risks, which are often long-term, large-scale processes, where systemic understanding is still emergent.

There is a trade-off, however, between the cost of obtaining and analysing information, and the associated benefit. It is no surprise that the principal environmental risks which research providers currently analyse are those which can be relatively easily measured through the use of publicly available datasets: greenhouse gas (GHG) and other air pollutant emissions, water and climate risks, with only a few research providers offering services related to agricultural or natural resource depletion risks. One reason for this may be that understanding such risks requires the ability to analyse large volumes of

spatial data, for example using Geographical Information Systems (GIS), which traditional research providers typically do not use (Cojoianu et al. 2015).

We have demonstrated that it is possible to derive a suitable evidence base to support a comprehensive, industry- and geography-specific assessment of natural capital risks for smaller-scale loans in agriculture, using wheat farming in Australia as a case study. In principle, this suggests that the same generic approach could be followed to develop similar frameworks suitable for other sub-sectors and geographies.

However, the exercise has not been without challenges. Natural processes are often characterised by complexity and interconnectedness. While it is relatively easy to identify high-level natural capital risk categories, we discovered that most of these are in fact multi-dimensional: for example, rainwater availability is a function of quantity, timing, reliability and water use efficiency, each of which can be associated with distinct risks. These sub-factors can combine in various ways, each entailing different risks: for example, the risk of insufficient water availability during the critical growing stages involves a different combination of quantity and timing issues to the risk of excessive rainfall at harvest. The multi-dimensionality of environmental risks can be observed at multiple levels and often involves cross-linkages with other environmental risks: for example, water use efficiency is itself a function of various factors including soil characteristics, nitrogen supply, weed cover and so forth. An assessment framework based on dissection of multi-dimensional risks in order to evaluate individual risks may overlook some systemic cross-linked issues.

A related challenge has been to bridge the gap between the financial sector's desire for an unambiguous answer to what seems a simple question – is this loan an acceptable risk? – and the complexity, uncertainty and heterogeneity of the reality on the ground. We have had to use our own judgement in some cases to distil what seem to be the key

risk factors from a mass of detailed, sometimes contradictory, scientific and industry statements. Our presentation of any given risk may well be regarded as a gross over-simplification by an expert in that particular area. Whilst the evidence base we have presented can undoubtedly be refined and improved, a balance must be struck between exactitude and practicality. No metric will ever perfectly capture any given risk – to be useful, it need only perform better than the current alternative, which for many of these factors is no assessment whatsoever.

Some risks are less challenging to evaluate than others. For example, energy use and GHG emissions are relatively easy to monitor and to price with a shadow cost of carbon, and therefore we have not discussed these risks further in this paper. Soil health risk factors are at the other end of the spectrum, being highly complex, interconnected, and long-term issues.

Finally, we have shown that many sources of useful quantitative data to assess natural capital risk factors exist – at least in a developed country such as Australia – but also that qualitative data will almost always also be required to obtain a view of how able the borrower is to manage a particular risk. The ‘managed risk’ situation is what is most relevant to the lender, as opposed to only the underlying physical risk on its own. Furthermore, the fact that most risks can be managed proactively suggests that there is a role for natural capital risk assessment in ongoing monitoring and farmer engagement, and not only at the initial credit assessment stage.

We have only been able to infer financial materiality at the level of the farmer from evidence of the magnitude of physical risks and generic financial evidence such as sector-level costs. Further research to evaluate the impact on farm financial performance of any individual risk factor, or ideally all of them in combination, would be extremely useful.

6 Fin vs. Tech: Fintech Start-Up Emergence and Innovation in the Financial Services Incumbent Sector

6.1 Introduction

"Cryptocurrencies - everything you don't understand about money combined with everything you don't understand about computers." John Oliver (2018)

Technology has long been at the core of the development of financial services. During the 20th century, financial technology has been marked by the introduction of the ATM in 1967 by Barclays, followed by the transition from the analog era of financial technology to the digital era of electronic payment systems, and last but not least, by the emergence of computerized securities trading and online banking (Arner, Barberis and Buckley, 2016; Wójcik and Cojoianu, 2018a). In the aftermath of the global financial crisis (GFC), we are witnessing the rise of a new wave of financial innovations, known as fintech, powered by advances in data science and computational power to store and analyse large financially relevant datasets. The rise of fintech has been further facilitated by the penetration of smartphone technology, and legitimised by the low levels of trust in financial institutions compared to technology companies (Rooney, 2018; Sapienza and Zingales, 2012).

One of the most visible features of the fintech movement has been the rise of start-ups, which offer solutions ranging from mobile payments and automated investment advice to cryptocurrencies and crowdfunding platforms. However, financial services incumbents as well as established technology companies are also playing an important role in the fintech ecosystem. Financial services companies have spent in excess of $480 billion on information technology in 2018 (IDC, 2018), and many have engaged with fintech innovation. For example, JPMorgan spent over $600 million in fintech initiatives in 2016, focused on revamping their digital services and partnering with fintech start-ups

(Dimon, 2017) and recently announced plans to launch its own cryptocurrency, the JPM coin. Goldman Sachs invested mainly in payments technologies, while Banco Santander is most active through its venture capital arm InnoVentures by directly investing in fintech start-ups (Crunchbase, 2018).

Given these new developments in financial intermediation, how can we best explain the spatial emergence of fintech innovations in the form of both start-ups and innovations developed by financial services incumbents? Is the emergence of fintech start-ups due to knowledge spillovers originating in the incumbent financial sector, or in the incumbent technology sector? How can the fields of entrepreneurship, industrial dynamics and economic geography complement financial intermediation theory in explaining changes in financial intermediation?

Early financial intermediation theorists contended that in resource allocation models based on assumptions of perfect and complete markets, there would be no need for intermediaries (Scholtens and van Wensveen, 2000). In reality, it is inefficient for households, companies or governments to individually hold savings and invest without benefiting from the economies of scale offered by savings institutions (Clark, 2017). In addition, potential borrowers would face very high fundraising costs in trying to convince individual households of their credit-worthiness and crowdsource their capital. In this respect, overcoming high transaction costs, participation costs and the issues associated with asymmetric information became the main accepted explanation as to why financial intermediaries exist (Allen and Santomero, 1998).

But this explanation is not satisfactory, when trying to answer how a pension fund is different from a commercial bank, or what the drivers are behind the rise of crowdfunding platforms, robo-advisors, cryptocurrencies or digital wallets. Modern financial intermediation theorists suggest that instead of conceptualising financial

institutions as operating in a static perfect market, scholars should "assume a more dynamic concept in which new markets are developed for new products, where financial institutions do not act as 'agents' who intermediate between savers and investors […], but are independent market parties that create financial products and whose value added to their clients is the transformation of financial risk, term, scale, location, and liquidity" (Scholtens and van Wensveen, 2000, p. 1249).

This dynamic view of industries has been long held by industrial dynamics, economic geographers and entrepreneurship scholars, starting with the works of Alfred Marshall and Joseph Schumpeter (Capasso et al., 2015; Frenken et al., 2015). Industrial dynamics studies seek to explain the heterogeneity and dynamics of new firms, industries and regional clusters, and combine insights from economic geography to provide a spatial and time contextual understanding of industry evolution. As far as new firms are concerned, entrepreneurship scholars have provided ample evidence for understanding the sources of entrepreneurial opportunities, chief among these being new knowledge (Acs et al., 2009; Audretsch, 1995; Audretsch and Keilbach, 2007a).

In this respect, this paper studies the rise of fintech innovation through the lens of start-ups and financial services incumbents as independent market agents that adapt and provide innovative products in response to client demand (Lo, 2012; Clark, 2017). We draw on theories grounded in industrial dynamics and entrepreneurship scholarship and we also incorporate insights from the relatively new field of financial geography, which proposes, at a conceptual level, to study capitalism top-down and bottom up through the decision making , social practices and geographical scope of financial institutions (Clark, 2005).

Our study investigates the likely factors that may influence fintech start-up emergence and fintech innovation by financial services incumbents across 21 countries

and 226 OECD regions, between 2007 and 2016. We find that fintech start-up emergence is positively related to new knowledge created in the IT sector and not in the incumbent financial sector, positively related with the regional IT productivity as well as with the retail financial deposit amounts at the national level. On the other hand, financial services incumbents focus their innovation efforts in regions and countries where their high-margin clients and high-income subsidiaries are located, which suggests that after the financial crisis much of the underserved clients, including retail customers and SMEs, may have remained underserved unless they were able to access alternative financial services provided by new fintech entrants.

This paper is structured as follows. In Section 2, we review some of the documented drivers of fintech innovation in literature and we illustrate how the knowledge spillover theory of entrepreneurship, regional labour productivity as well as demand for financial services can explain fintech innovation across both start-ups and financial services incumbents. Section 3 presents our empirical model and data. Section 4 provides descriptive statistics of our panel dataset, while Section 5 discusses the results of our empirical investigation.

6.2 Theoretical background and hypotheses

6.2.1 Drivers of fintech innovation

Given the relatively recent emergence of the fintech sector, there are only a handful of quantitative studies looking at the factors that facilitated the rise of fintech and several qualitative accounts.

Arner et al. (2016) provides a history of the interlinkage between finance and technology going back 150 years and illustrates that the distinct features of the fintech revolution after 2008 are the emergence of new actors that provide financial services, fintech start-ups and established technology companies, and the increased rate of

technological innovation in financial intermediation. The financial crisis, underpinned by the modern digital infrastructure and the advances in data science, have placed the highly trusted technology sector incumbents in a good position to challenge the financial sector in the provision of financial services (Wójcik and Cojoianu, 2018a). This is confirmed by the findings of Broström et al. (2018), who find a positive association between distrust in banks and participation on peer-to-peer lending platforms.

Haddad and Hornuf (2018) study the country level factors which likely influence fintech entrepreneurship using a global dataset over the period 2005 – 2015, and find that the availability of venture capital financing, the number of secure internet servers and mobile subscriptions are positively related with fintech entrepreneurship. In contrast, the difficulty of accessing loans by companies is positively related with emergence of fintech start-ups. Cumming and Schwienbacher (2018) investigate fintech venture capital funding patterns across 63 countries and find that after the financial crisis, investments in fintech start-ups are more likely to take place in countries with weaker regulatory enforcements and by venture capitalists that have less experience with prior VC boom and bust cycles. However, these deals tend to faceless successful exit rates, particularly when fintech start-ups are located in countries without a major financial centre.

Are fintech innovations profitable for innovators? Chen et al. (2018) analyse fintech innovation in the US over the period 2003 – 2017 and show that fintech patent grants are positively related with better financial performance of the companies that own them, particularly if these innovations are blockchain related. Blockchain, Internet of Things (IoT), and robo-advising related patents are found to provide the greatest returns for financial sector incumbents.

6.2.2 IT sector and financial services knowledge spillovers

The knowledge spillover theory of entrepreneurship is a theory developed by Audretsch (1995), which has been since refined by Audretsch and Keilbach (2007) and Acs et al. (2009), and which suggests that an important source of entrepreneurship opportunities is new knowledge created in incumbent firms, universities or research organisations, which for various reasons remains uncommercialised. This theory stands in stark contrast with early entrepreneurship research that considered the source of entrepreneurial opportunities as constant, and explained differences in propensity to engage in entrepreneurship through differences in cognitive abilities (Krueger, 2003).

But why would entrepreneurs choose to pursue new knowledge-related commercial opportunities that are left uncommercialized by knowledge creators? Acs et al. (2009) argue that it is the divergence in the valuation of new knowledge between new entrants and knowledge creators, as well as the higher ability of new entrants to bear the costs of uncertainty associated with uncommercialised knowledge. The appropriation of new knowledge by potential new entrants can occur through numerous channels including: supplier-customer relationships, formal and informal professional associations and the movement of highly skilled human capital (Feldman and Kelley, 2006). This dynamic knowledge spillover process also depends on the capacity of potential new entrants to absorb newly created knowledge and to employ it in a commercial context (Qian, 2018; Qian and Acs, 2013).

There is considerable evidence that knowledge spillovers are localised (Audretsch and Lehmann, 2005; Qian et al., 2013), particularly as far as human capital mobility and face-to-face interaction are concerned (Qian, 2018). While some economic geographers argue that geographic proximity in itself is neither necessary nor sufficient for knowledge

spillovers to occur, there is wide agreement that geographic proximity reduces the cost of accessing and absorbing knowledge spillovers (Audretsch and Lehmann, 2005).

While KSTE establishes new knowledge as the main source of entrepreneurial opportunities, the literature has addressed the relevance of the characteristics of knowledge creators in a limited way. In other words, it is unclear how different types of organisations and individuals, who create knowledge ultimately influence whether KSTE occurs and how efficient it is. Studies usually analyse the effect of one type of knowledge creator on new venture creation (Audretsch and Lehmann, 2005), or ignore the source of knowledge altogether.

Hence, the present study, through the fintech research setting, can contribute to the KSTE literature by showing how knowledge created in different organisational settings may or may not result in entrepreneurship outcomes. Scholars analysing the fintech industry have argued that it is predominantly data science and digital technology advances in the technology sector in the past 10 years that have enabled the rise of fintech (Arner, Barberis and Buckley, 2016; Chen, Wu and Yang, 2018; Wójcik and Cojoianu, 2018a), but no formal statistical test has been carried out to test this, as well as conversely, to test whether the fintech movement is related to new knowledge generated in the financial sector. We therefore hypothesise that:

H.1a. New regional knowledge created in the IT sector is positively related to new regional fintech venture creation.

H.1b. New regional knowledge created by financial services incumbents is not related to the creation of new fintech ventures.

6.2.3 High-tech or high-finance talent

Human capital externalities have been long considered a key variable in economic growth models (Acs and Armington, 2004) while entrepreneurs are seen as key agents of growth (Acs et al., 2016). This has prompted scholars to focus on the link between

entrepreneurship outcomes and human capital at the individual, venture and regional level (Acs and Armington, 2004; Marvel et al., 2016). The extensive literature review of Marvel et al. (2016) highlights that human capital is crucial in the entrepreneurship context as human capital is dynamically engaged in accumulating, creating and exploiting knowledge towards the creation and growth of new ventures. Besides being one of the channels through which knowledge spillovers occur, the task of acquiring and organising resources for launching and growing a venture relies on the available human capital (Gimeno et al., 1997).

In emerging industries born at the intersection of established sectors, the degree to which the human capital of an established sector influences new start-up formation is less known. Building on the knowledge spillover hypothesis (H.1), we hypothesise that:

H.2a. Regional IT workforce productivity is positively related to new fintech start-up formation

H.2b. Regional finance sector workforce productivity is not related to fintech start-up formation.

If knowledge created in the IT sector rather than the financial sector is more important to new fintech start-ups, it follows that the highly innovative IT workforce is more likely to be able to exploit the knowledge in a fintech context, or that in the early venture stage process the IT workforce is a more critical input than financial services talent.

The technology functions of financial services incumbents are typically fulfilled in mid and back offices, which are more closely linked with geographies of high-technology clusters than geographies of front offices located in financial centres (Wójcik, 2011b). This is particularly true for credit and insurance activities. In the aftermath of the GFC, the technology function has been interwoven with the compliance and risk management functions, which are also core mid and back office functions. JPMorgan's plan to open an 1,000 people Silicon Valley fintech office by 2020, motivated by the opportunity to hire

from a highly skilled software engineering talent pool, is evidence that financial services incumbents see IT talent as the main competitive edge in the fintech revolution (Henry, 2018).

A geography of high-tech asset management also emerges by examining the corporate structure and hiring trends of advanced asset managers such as BlackRock or Vanguard. Haberly et al. (2018) provide an in-depth account of BlackRock's technological expertise and show that in early 2018, 42% of BlackRock's job listings were software engineering related. These new roles are advertised overwhelmingly in back office technology centers such as Budapest, Gurgaon and Edinburgh, which highlights an underlying trend in asset management of moving jobs in regions and cities which have lower costs of living but highly skilled technology expertise (Tett, 2018). This combination of cost-cutting and technological upgrading across the financial sector has been also noted by Wójcik and Cojoianu (2018b).

Hence, we hypothesise that innovation in the financial services incumbent sector is also more likely to occur in geographic regions with a highly skilled IT workforce, while the regional expertise in finance is less relevant.

H.3a. Regional IT workforce productivity is positively related to fintech innovations by financial services incumbents.

H.3b. Regional finance workforce productivity is not related to innovation by financial services incumbents.

6.2.4 Fintech demand factors

In the aftermath of the financial crisis, many customers have remained underserved, particularly retail customers and SMEs, as bank lending dried up (Wójcik and Cojoianu, 2018a). The fintech opportunity for start-ups has manifested itself in serving these overlooked customers while providing them with more affordable financial products. Philippon (2015) show that the cost efficiency of financial intermediation in the

US has remained unchanged for the past 130 years at around 2%, despite the numerous advances in technology. This means that the benefit of economies of scale from financial technology have not been passed on to the final consumer by the financial services incumbents.

This is starting to change post financial crisis as Fuster et al. (2018) demonstrate, using US-wide data on mortgages, that fintech lenders in the US process mortgage applications 20% faster than the incumbent banking sector, without incurring the costs of higher defaults. As many labour-intensive tasks are replaced by data science infrastructure and systems, many financial services products can be provided more efficiently and more affordably. For example, Grennan and Michaely (2018) show that data services from fintech start-ups compete with sell-side investment content products of traditional financial services providers. While fintech start-ups may cater for underserved financial services customers and in some respects compete with financial services incumbents, there are many fintech solutions which start-ups look to sell to the incumbent financial sector or to partner with incumbents in order to access their distribution channels (Wójcik and Cojoianu, 2018a). In this light we hypothesise that fintech start-ups are likely to serve businesses in those countries where financing has dried up. In addition, we expect that some fintech companies will compete with banks for retail customers but at the same time, banks can also be the customers of fintech start-ups. Hence, our hypotheses seek to test whether:

H.4a. Countries with lower levels of capital raised by the corporate sector yield higher levels of regional fintech start-ups.

H.4b Countries with bigger retail market for financial services yield a higher number of regional fintech start-ups.

H.4c. Regions with higher presence of financial services incumbents yield a higher number of fintech start-ups.

To explain the emergence of fintech innovations developed by financial services incumbents, we utilize Christensen's (1997) innovator dilemma framework and focus on the demand factors expected to influence fintech innovation. Christensen and Bower (1996) and Christensen (1997) argue that an incumbent's innovation endeavours are constrained by the preferences of their existing customer base. Hence, incumbents prefer to innovate incrementally rather than disrupt the way their current customers operate. Christensen et al. (2018) explains that the pursuit of profitability usually prompts incumbents to move up-market rather than down-market. In the case of fintech, this theory would translate into the hypothesis that financial services incumbents innovate in higher margin markets where they already hold a significant customer base.

H.5. Regions with a bigger market for financial services yield a higher number of fintech innovations by incumbent companies.

6.3 Data and methodology

6.3.1 Dependent variables

New regional fintech ventures

The start-up dependant variable is the annual count of new fintech entrants by region. We map high-growth start-ups to regions using companies' headquarters addresses obtained from Crunchbase and a mapping tool provided by the OECD which allows us to match company addresses with Territorial Level 2 (TL2 regions) of OECD countries (OECD, 2018). This allows international comparability given that national statistical offices use the OECD classification to collect different policy relevant datasets and governments use these to set regional policies.

In retrieving a global sample of fintech start-ups, we rely on the Crunchbase[20] and CBInsights[21] commercial databases. Both companies provide data intelligence services

[20] https://www.crunchbase.com/
[21] https://www.cbinsights.com/

on innovative start-ups to investors, companies and governments around the world. In this respect, the database consists of high-growth potential and innovative companies rather than an aggregation of country level business registries. Following the approach of Wójcik and Cojoianu (2018), we conduct extensive keyword searches on Crunchbase, and complement it with other companies covered only by CBInsights (See **Appendix A.6.1**). In this way, we construct a global sample of 5,381 companies founded between 2006 and 2016, with complete headquarter address details, including 2,547 companies (47%) for which data on funding was available.

We narrowed down the company list for our 21 OECD target countries and 226 regions for which we were able to obtain robust coverage of explanatory variables. Hence, our sample covers 3,807 new fintech ventures established over 2007 – 2016. Our explanatory variables are lagged one year and cover the period 2006 – 2015. To provide further context to our sampled companies, we examine their websites to check whether they have been correctly classified as fintech start-ups by Crunchbase and CBInsights and we classify them into fintech sub-sectors based on the nature of their activities. We detail these fintech sub-sectors in **Appendix A.6.2**.

New regional fintech patents in financial services incumbents

We construct a regional variable of fintech innovation in financial services incumbents based on the fractional count of fintech patent applications of asset managers, banks, insurance companies and stock exchanges across our 21 target countries and 226 regions. The fractional counts are based on inventor address, or where this was not available, on the applicant's address. We include patent applications who have an asset manager, bank, stock exchange or an insurance company as either the assignee or as the applicant.

We conduct patent searches using the PatSeer[22] platform, which links patents with the companies that own them. We first build our representative sample of financial services incumbents which includes the top 500 asset managers by assets under management in 2016 (Willis Towers Watson, 2017), the world's top 2000 investment and commercial banks by fees between 2000 – 2015, a list of 776 listed insurance companies which we identified by using the SASB[23] industry classification database and a list of 186 stock exchanges from around the world from Datastream. The commercial and investment banking dataset was built using Dealogic[24] data and includes all banks with more than $4.8 million in total fees over the 2000 – 2015 period.

We review the identified patents from PatSeer covering the above sample of financial services incumbents to determine which are related to fintech and to categorise innovations into the seven fintech sub-sectors, which we used to classify the fintech start-ups sample. We then shortlist the patents and map each patent to the region(s) of innovator / applicant to create a fractional count.[25]

6.3.2 Independent variables

We test H.1a,b by using the fractional regional patent application counts in the IT sector as a proxy for new regional IT knowledge. Regional IT patent data was collected from the OECD REGPAT database which allows for quantification of the innovation output over more than 2,000 TL3 regions in the OECD and across several technologies. The OECD employs robust patent search methodologies to identify all patent applications to the EPO, USPTO and JPO as well as those filed under the Patent Cooperation Treaty (PCT).

[22] www.patseer.com
[23] www.sasb.org/approach/sics
[24] https://www.dealogic.com/
[25] For example, if a patent has two inventors, one from London and one from New York, each region gets assigned a count of 0.5

From this total regional IT patent application count we subtract the regional IT patent count in financial services incumbents to quantify the total new IT knowledge generated outside financial services incumbents. In this way, we can distinguish between the effects of both new IT knowledge generated in financial services incumbents as well as knowledge generated in the mainstream IT sector, on new fintech start-up creation. To study the relative influence of financial vs. technology workforce on fintech innovation, we measure the workforce productivity of both the IT sector and the financial and insurance sector at the regional level. We measure productivity as the ratio of the gross value added (GVA) to total employment within each sector. The data is retrieved from the OECD iLibrary and aims to test H.2a,b and H.3a,b.

To analyse the role of the demand for retail financial and insurance services we use data from S&P Global which quantifies the country volume of retail bank deposits and two variables from Oxford Economics: the percentage of financial services and percentage for insurance in total household spending at the national level, since unfortunately such data is not available at regional level (H.4a. and H.5.).

The country-level demand for investment banking services is constructed from the Dealogic database by summing the total deal volume across loans, M&A, equity and bond issuance by the headquarter country of the companies raising money or involved in M&A activity (in support of H.4b. and H.5.).

We build an additional variable to control for centres and regions with high investment banking activity by quantifying the total fees of investment bank subsidiaries at the regional level. The fees and the addresses of subsidiaries come from Dealogic (H.4c. and H.5.).

6.3.3 Control variables

We use several regional and country level control variables to account for other factors which may influence fintech start-up entry. High-growth technology companies are known to be more likely to emerge in high-income regions (measured by GDP per capita), in regions which have higher availability of start-up capital (quantified by total equity and debt financing to start-ups from Crunchbase) as well as in regions with higher number of knowledge producing organisations (measured by the number of research institutes per capita from the GRID[26] database). We also control for the level of retail customer distrust in the banking sector (Gallup World Poll data) (Broström et al., 2018; Guiso et al., 2013).

Finally, we include the penetration of internet broadband and mobile phone subscription services per 100 people at the national level using data from the World Economic Forum and R&D expenditure as a percentage of GDP to measure country level innovation related spending (see **Appendix A.6.3** for a summary of all variables).

6.3.4 Model specification

Our analysis is conducted at the regional level, with the data organised in a balanced panel between 2007 – 2016. Both the start-up entry dependent variable and the financial services incumbent patent count are non-negative count integers. In line with the work of York and Lenox (2014), we employ a random effects model. Allison and Waterman (2002) show that a fixed effects estimator is biased for a negative binomial model and cannot control for varying covariates. To further control for temporal and spatial variations in our models, we include year and regional fixed effect. For robustness, we also cluster standard errors at the regional level for all models (Petersen, 2008). We also conduct robustness tests by excluding New York and London from our

[26] https://www.grid.ac/

models to ensure that the results are not driven by either geography. All regressors in our models are lagged by one year. The functional forms of our models are illustrated below:

$$New\ Fintech\ Ventures_{i,t} = \exp[(\beta_1 * \ln(IT\ Knowledge_{i,t-1}) +$$
$$\beta_2\ * ln(Incumbent\ Fintech\ Knowledge\ _{i,t-1}) +$$
$$\beta_3\ * ln(IT\ Sector\ Productivity_{i,t-1}) +\ \beta_4 * \ln(Financial\ Sector\ Productivity_{i,t-1}) +$$
$$\beta_5 * \ln(Retail\ Financial\ Services\ Spending_{i,t-1}) + \beta_6\ * ln(Corporate\ Inv.Bank\ Serv.Demand_{i,t-1}) +$$
$$\beta_7\ * ln(Supply\ of\ Inv.Bank.Services\ _{i,t-1}) + Control\ Variables +\ \mu_t + \varepsilon_{i,t}]$$

$$Financial\ Serv.Incumbent\ Fintech\ Innovation_{i,t} = \exp[(\ \beta_1\ * ln(IT\ Sector\ Productivity_{i,t-1}) +$$
$$\beta_2 * \ln(Financial\ Sector\ Productivity_{i,t-1}) +\ \ \beta_3 * \ln(Retail\ Financial\ Services\ Spending_{i,t-1}) +$$
$$\beta_4\ * ln(Corporate\ Inv.Bank\ Serv.Demand_{i,t-1}) + \beta_5\ * ln(Supply\ of\ Inv.Bank.Services\ _{i,t-1}) +$$
$$Control\ Variables +\ \mu_t + \varepsilon_{i,t}]$$

6.4 Synthesis of results

6.4.1 Fintech entrepreneurship

Model 1a (**Table 6.1**) shows how the control variables are related to regional fintech start-up creation between 2007 – 2016. Given that it is a log-log model, the coefficients should be interpreted as a 1% change in the coefficient corresponding to β% in the dependent variable. We find that GDP per capita is strongly and positively related to new regional start-ups ($\beta = 2.33$, $p < 0.001$). A positive relationship also exists between regional research institutes per capita and new start-up creation (RI_Cap: $\beta = 0.35$, $p < 0.1$). R&D, the level of trust in financial institutions and broadband subscriptions at the country level seem to not be related to new fintech ventures, whereas country level mobile phone subscriptions are negatively partially correlated with fintech start-ups ($\beta = -1.45$, $p < 0.001$).

In models 1b-f we introduce sequentially supply and demand factors as well as regional productivity in the IT and financial sector. Given that coefficients are stable with the introduction of each new set of variables, here we report only the coefficients for the

full model 1f. As expected, regional start-up funding availability is positively related to new fintech venture creation ($\beta = 0.33$, $p < 0.001$). In support of H.4b,c we find that both the regional presence of high earning financial services incumbents and the country level value of retail deposits are positively related to fintech venture creation ($\beta = 0.11$, $p < 0.001$). On the other hand, we find no evidence of a statistically significant relationship between the country level volume of funds raised by corporates and fintech start-up creation, which means that H.4a does not hold. Furthermore, as hypothesised (H.2a,b) we find that the regional productivity of the IT sector is strongly and positively related to the founding of new fintech ventures ($\beta= 0.49$, $p < 0.05$), whereas there is no relationship between the regional productivity of the financial sector and new start-ups.

To study the relative effect of knowledge generated within financial services incumbents vs. knowledge generated in the IT sector on new fintech venture creation, we further include regional IT patents as well as fintech incumbent patents (models 2a-c in **Table 6.2**). Given the coverage of the patent dataset, we are able to study this relationship only over the period 2007 – 2014. Considering the high correlation between regional start-up funding and regional IT patents, we orthogonalize the start-up funding measure and include only the information that is not explained by the IT patent variable (i.e. the residual of a linear regression seeking to explain variation in start-up funding with IT patents). In these models, we find strong evidence that IT knowledge generated outside the incumbent financial sector is positively related to new regional fintech start-up rates ($\beta = 0.65$, $p < 0.001$), whereas regional financial sector incumbent knowledge has no effect on new start-up creation

Table 6.1: Fintech start-up models.

	Controls	**Corporate Demand of Fin. Services**	**Corporate and Retail Demand of Fin. Services**	**Fin Sector Productivity**	**IT Sector Productivity**	**Fin & IT Sector Productivity**	**Robustness Test Cluster Robust S.E.**
	Model 1a	**Model 1b**	**Model 1c**	**Model 1d**	**Model 1e**	**Model 1f**	**Model 1g**
GDP_Capita	2.33***	0.97**	0.98**	0.95**	0.75*	0.80*	0.80*
	(0.40)	(0.31)	(0.32)	(0.33)	(0.32)	(0.33)	(2.34)
RI_Cap	0.35^	0.15	0.17	0.17	0.14	0.15	0.15
	(0.21)	(0.14)	(0.15)	(0.15)	(0.14)	(0.14)	(1.03)
RD_GDP	0.40	-0.06	0.06	0.05	-0.03	-0.02	-0.02
	(0.34)	(0.27)	(0.28)	(0.28)	(0.28)	(0.28)	(-0.07)
Lack_of_Trust	0.20	0.23	0.37*	0.38*	0.28	0.26	0.26
	(0.16)	(0.16)	(0.17)	(0.17)	(0.17)	(0.18)	(1.39)
Broadband_Subs	0.32	0.30	0.24	0.25	0.27	0.26	0.26
	(0.30)	(0.27)	(0.27)	(0.27)	(0.27)	(0.27)	(0.72)
Mobile_Ph_Subs	-1.45***	-0.94**	-1.12**	-1.11**	-1.09**	-1.11**	-1.11*
	(0.40)	(0.36)	(0.41)	(0.41)	(0.40)	(0.40)	(-2.30)
Start_Up_Funding		0.35***	0.34***	0.34***	0.33***	0.33***	0.33***
		(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(6.75)
Reg_Inv_Bank_Activity		0.11***	0.11***	0.11***	0.11***	0.11***	0.11***
		(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(3.61)
Country_Inv_Banking_Demand		0.02	-0.04	-0.04	-0.08	-0.08	-0.08
		(0.05)	(0.05)	(0.05)	(0.05)	(0.06)	(-1.45)
Retail_Deposits			0.08**	0.08**	0.08**	0.07*	0.07**
			(0.03)	(0.03)	(0.03)	(0.03)	(2.63)
Retail_Fin_Spending			0.15	0.17	0.25	0.21	0.21
			(0.19)	(0.21)	(0.20)	(0.21)	(1.03)
Retail_Ins_Spending			0.01	0.01	0.12	0.13	0.13
			(0.20)	(0.20)	(0.20)	(0.20)	(0.50)
Prod_Fin_Insurance				0.04		-0.09	-0.09
				(0.14)		(0.15)	(-0.60)
Prod_IT					0.45*	0.49*	0.49^
					(0.18)	(0.20)	(1.77)
AIC	3890.18	3778.58	3775.96	3777.88	3772.22	3773.86	3775.04
BIC	3993.20	3898.77	3913.31	3920.96	3915.30	3922.66	3923.84
Log Likelihood	-1927.09	-1868.29	-1863.98	-1863.94	-1861.11	-1860.93	-1861.52

***p < 0.001, **p < 0.01, *p < 0.05, ^p < 0.1. Standard errors in parentheses (model 1g – region robust standard errors). 2260 Region-Year observations (226 regions over 10 years: 2007 – 2016). Year fixed effects included.

Table 6.2: Knowledge spillovers effects on fintech entrepreneurship.

	IT Sector Knowledge Spillover	**Financial Sector Knowledge Spillover**	**IT and Financial Sector Knowledge Spillover**	**Robustness Test Cluster Robust S.E.**
	Model 2a	**Model 2b**	**Model 2c**	**Model 2d**
GDP_Capita	0.45	1.42***	0.44	0.44
	(0.30)	(0.43)	(0.30)	(1.49)
RI_Cap	-0.10	0.19	-0.10	-0.10
	(0.13)	(0.19)	(0.13)	(-0.77)
RD_GDP	-0.74**	0.10	-0.72**	-0.72**
	(0.27)	(0.36)	(0.27)	(-2.84)
Lack_of_Trust	0.08	0.16	0.10	0.10
	(0.19)	(0.20)	(0.19)	(0.44)
Broadband_Subs	0.03	0.31	0.03	0.03
	(0.27)	(0.31)	(0.27)	(0.08)
Mobile_Ph_Subs	-1.29**	-1.26*	-1.28**	-1.27***
	(0.45)	(0.49)	(0.44)	(-2.46)
Start_Up_Funding	0.28***	0.15***	0.27***	0.27***
	(0.04)	(0.04)	(0.04)	(6.07)
Reg_Inv_Bank_Activity	0.08**	0.13***	0.08**	0.07**
	(0.02)	(0.03)	(0.02)	(2.94)
Country_Inv_Banking_Demand	-0.12*	-0.01	-0.12*	-0.12*
	(0.06)	(0.07)	(0.05)	(-2.37)
Retail_Deposits	0.06*	0.08*	0.06*	0.06**
	(0.03)	(0.03)	(0.03)	(2.61)
Retail_Fin_Spending	0.48*	0.32	0.47*	0.47*
	(0.20)	(0.28)	(0.20)	(2.27)
Retail_Ins_Spending	0.18	0.20	0.19	0.19
	(0.20)	(0.25)	(0.20)	(0.95)
Prod_Fin_Insurance	0.01	-0.22	0.01	0.02
	(0.15)	(0.19)	(0.15)	(0.11)
Prod_IT	0.52**	0.66**	0.51*	0.51*
	(0.20)	(0.24)	(0.20)	(2.26)
IT_Knowledge	0.65***		0.65***	0.65***
	(0.05)		(0.05)	(15.43)
Incumbent_Fintech_Knowledge		0.06	0.04	0.04
		(0.05)	(0.05)	(0.72)
AIC	3015.22	3146.90	3016.40	3017.46
BIC	3152.72	3284.40	3159.40	3160.45
Log Likelihood	-1482.61	-1548.45	-1482.20	-1482.72

***p < 0.001, **p < 0.01, *p < 0.05, ^p < 0.1. Standard errors in parentheses. (model 2d – region robust standard errors). 1808 Region-Year observations (226 regions over 8 years: 2007 – 2014, given IT patent data availability). Year fixed effects included.

6.4.2 Fintech innovation in financial services incumbents

In a similar manner, we analyse the likely factors influencing fintech innovation in financial services incumbents. First, we consider the effect of control variables on their own. Model 3.a in **Table 6.3** illustrates a positive relationship between GDP per capita and incumbent fintech patents ($\beta = 3.74$, $p < 0.01$). We also unveil a statistically significant relationship between the trust levels in financial institutions by retail customers and incumbent fintech innovation, which shows that incumbents tend to innovate more in countries which have higher level of trust in the financial services sector ($\beta = -1.07$, $p < 0.1$). These coefficients tend to be less stable though as we expand our model. We further discuss the results including our key independent variables, which across the different models 3.b-f. For simplicity, we focus on the full model 3f. We find no evidence in support of H.3a,b which states that fintech incumbent innovation is also more likely to occur in regions with high IT sector productivity rather than high financial sector productivity. Neither indicator is statistically significant in our models.

We do however find strong support for the fact that incumbents innovate in regions and countries where their existing revenue streams are highest on both the corporate and retail side (H.5). There is a positive and statistically significant relationship between both the regional supply of banking services ($\beta = 0.28$, $p < 0.001$) and country level demand for corporate banking products ($\beta = 0.67$, $p < 0.001$) with financial services incumbent fintech innovation activity. On the retail side, while the total amount of country level retail deposits does not correlate with financial services incumbent innovation activities, the higher the percentage of their disposable income that retail customers spend, the higher the incumbent innovation activities are. This provides support for the hypothesis that financial services incumbents may be focusing on their high-end customers, rather than the markets that were underserved in the wake of the global financial crisis.

Table 6.3: Fintech innovation in financial services.

	Controls	Corporate Demand of Fin. Services	Corporate and Retail Demand of Fin. Services	Fin Sector Productivity	IT Sector Productivity	Fin & IT Sector Productivity	Robustness Test Cluster Robust S.E
	Model 3a	**Model 3b**	**Model 3c**	**Model 3d**	**Model 3e**	**Model 3f**	**Model 3g**
GDP_Capita	3.74**	1.57	2.10^	1.95^	1.46	1.40	1.54
	(1.29)	(1.06)	(1.11)	(1.17)	(1.17)	(1.20)	(1.37)
RI_Cap	0.50	0.95^	0.68	0.64	0.65	0.63	0.84^
	(0.63)	(0.52)	(0.56)	(0.56)	(0.54)	(0.54)	(1.70)
RD_GDP	-0.91	-3.17**	-3.17**	-3.24**	-3.40**	-3.43**	-3.72**
	(1.01)	(1.09)	(1.13)	(1.14)	(1.13)	(1.14)	(-2.94)
Lack_of_Trust	-1.07^	-0.77	-0.65	-0.61	-0.76	-0.73	-0.63
	(0.55)	(0.52)	(0.53)	(0.54)	(0.54)	(0.55)	(-1.17)
Broadband_Subs	0.11	1.04	1.02	1.10	1.13	1.17	1.390
	(0.98)	(0.99)	(1.01)	(1.04)	(1.02)	(1.05)	(0.95)
Mobile_Ph_Subs	-1.43	-0.33	-0.03	-0.05	0.06	0.05	0.147
	(1.31)	(1.21)	(1.34)	(1.34)	(1.34)	(1.34)	(0.08)
Reg_Inv_Bank_Activity		0.28***	0.28***	0.28***	0.28***	0.28***	0.29***
		(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(3.44)
Country_Inv_Banking_Demand		0.95***	0.73***	0.73***	0.67***	0.67***	0.72**
		(0.18)	(0.20)	(0.20)	(0.20)	(0.20)	(2.96)
Retail_Deposits			0.09	0.09	0.09	0.09	0.09
			(0.08)	(0.08)	(0.08)	(0.08)	(0.94)
Retail_Fin_Spending			1.66*	1.80*	1.85*	1.92*	1.84^
			(0.75)	(0.81)	(0.75)	(0.81)	(1.78)
Retail_Ins_Spending			-0.01	-0.05	0.22	0.20	0.35
			(0.69)	(0.69)	(0.70)	(0.71)	(0.39)
Prod_Fin_Insurance				0.21		0.10	0.05
				(0.44)		(0.44)	(0.09)
Prod_IT					0.80	0.78	0.85
					(0.57)	(0.58)	(1.18)
AIC	1926.03	1888.89	1886.84	1888.63	1886.91	1888.85	1897.43
BIC	2029.04	2003.35	2018.47	2025.98	2024.26	2031.93	2040.51
Log Likelihood	-945.01	-924.44	-920.42	-920.31	-919.45	-919.42	-923.71

***p < 0.001, **p < 0.01, *p < 0.05, ^p < 0.1. Standard errors in parentheses (model 3g – region robust standard errors). 2260 Region-Year observations (226 regions over 10 years: 2007 – 2016). Year fixed effects included.

6.4.3 Heterogeneity across fintech subsectors

How do our hypotheses apply across fintech subsectors or different technologies? As far as fintech start-ups are concerned, regional IT knowledge is a strong and significant predictor across all fintech subsectors (H.1a, see

Table 6.4 and **Appendix A.6.2** for fintech subsector classification). Interestingly, in one case, we find evidence that regional knowledge in the incumbent financial sector is positively and significantly related to fintech start-ups targeting the capital markets subsegment (exchange / trading platforms, clearance and settlement technology and other bank-related back office functions).

This result is intuitive, as start-ups operating in these fields tend to co-operate with or sell to financial services incumbents, rather than choosing to compete. The regional IT sector productivity is related to new start-ups only in the data subsector, which focuses mainly on serving the data needs in the investment and lending decision making process ($\beta = 0.93$, $p < 0.001$). The regional finance and insurance sector productivity is positively and significantly related to new fintech start-ups in the insurance sector, which again shows, that in some fintech subsectors, the incumbent financial sector can be highly relevant ($\beta = 1.61$, $p < 0.001$).

We also investigate drivers of fintech innovation across different applications in the incumbent financial services sector (**Table 6.5**). The productivity of the regional IT sector is a strong factor related to whether incumbents innovate across investment and wealth management, data and insurance related applications, but unrelated to core banking innovation activities in payments and capital markets applications.

The regional financial sector productivity is positively and significantly associated only with incumbent innovations in insurance ($\beta = 2.90$, $p < 0.05$), and not in any other subsector. Our previous finding that incumbents tend to innovate in markets where their

clients are located or where they already have a strong presence holds across subsectors. For investment and wealth management applications, payments and capital markets solutions, incumbents innovate in countries where their client demand is highest, whereas digital infrastructure and data-related innovations, which tend to be related to the internal processes of financial organisations, emerge in regions where incumbents already have a strong presence.

Table 6.4: Fintech start-up subsector models.

Fintech Start-Ups	Investment and Wealth Management	Payments	Capital Markets	Digital Infrastructure	Data	Insurance	Cryptocurrencies
GDP_Capita	0.45	0.01	-0.65	-0.01	0.05	0.05	0.77
	(1.27)	(0.02)	(-1.10)	(-0.02)	(0.17)	(0.06)	(1.22)
RI_Cap	-0.30^	-0.29	0.26	-0.07	0.06	0.22	0.43
	(-1.92)	(-1.54)	(0.97)	(-0.49)	(0.49)	(0.56)	(1.51)
RD_GDP	-1.38**	-0.72	-1.22*	-0.72^	-1.15**	-2.56**	-0.30
	(-3.32)	(-1.63)	(-2.08)	(-2.10)	(-2.66)	(-2.97)	(-0.51)
Lack_of_Trust	0.40	-0.03	0.44	-0.07	0.44	1.59*	-0.09
	(1.06)	(-0.07)	(0.68)	(-0.17)	(1.03)	(1.89)	(-0.15)
Broadband_Subs	1.67**	0.18	-0.67	0.13	0.08	1.43	-0.89
	(2.81)	(0.38)	(-1.01)	(0.34)	(0.15)	(1.01)	(-0.95)
Mobile_Ph_Subs	-0.74	-0.67	-0.79	-1.11	-1.19	3.10	-2.81*
	(-1.14)	(-0.72)	(-0.82)	(-1.21)	(-1.54)	(1.61)	(-1.96)
Start_Up_Funding	0.42***	0.36***	0.44***	0.44***	0.37***	0.51**	0.33***
	(6.67)	(4.89)	(5.06)	(6.02)	(4.95)	(3.13)	(3.22)
Reg_Inv_Bank_Activity	0.07*	0.08*	0.05	0.04	0.07*	-0.18**	-0.02
	(2.11)	(2.35)	(0.99)	(1.50)	(2.07)	(-2.74)	(-0.38)
Country_Inv_Banking_Demand	0.01	-0.18	-0.02	-0.09	-0.17*	-0.09	-0.37***
	(0.21)	(-1.55)	(-0.15)	(-1.05)	(-2.08)	(-0.31)	(-2.77)
Retail_Deposits	0.04	0.12	0.11*	0.02	0.05	0.29	0.08
	(0.94)	(1.48)	(2.06)	(0.24)	(1.30)	(0.53)	(0.50)
Retail_Fin_Spending	0.32	0.48^	0.21	0.25	0.67*	1.78**	-0.21
	(1.39)	(1.65)	(0.54)	(0.85)	(1.99)	(3.06)	(-0.49)
Retail_Ins_Spending	0.03	-0.04	0.67^	-0.08	0.67*	1.38	0.37
	(0.12)	(-0.11)	(1.87)	(-0.22)	(1.82)	(1.61)	(0.74)
Prod_Fin_Insurance	0.31^	0.37^	0.12	-0.08	-0.03	1.61**	-0.24
	(1.84)	(1.82)	(0.40)	(-0.38)	(-0.14)	(2.70)	(-0.73)
Prod_IT	0.32	0.52	0.68	0.18	0.93***	-0.47	0.51
	(1.25)	(1.47)	(1.51)	(0.47)	(3.61)	(-0.61)	(0.95)
IT_Knowledge	0.70***	0.66***	0.69***	0.66***	0.64***	1.09***	0.70***
	(12.42)	(10.34)	(9.51)	(11.23)	(11.61)	(5.49)	(9.36)
Incumbent_Fintech_Knowledge	-0.02	0.08	0.27***	0.15^	0.11^	0.04	0.21
	(-0.24)	(0.75)	(3.51)	(1.65)	(1.68)	(0.20)	(1.52)
AIC	1555.84	1473.20	761.15	1362.42	1359.24	351.80	542.454
BIC	1698.84	1616.20	898.65	1505.42	1502.24	494.80	685.45
Log Likelihood	-751.92	-710.60	-355.57	-655.21	-653.62	-149.90	-245.22

***p < 0.001, **p < 0.01, *p < 0.05, ^p < 0.1. Cluster robust standard errors in parentheses. `1808 Region-Year observations (226 regions over 8 years: 2007 – 2014). Year fixed effects included. Model for capital markets is a random-effects poisson model with robust clustered standard errors given convergence issues with the negative binomial model.

Table 6.5: Fintech subsector innovation in financial services incumbents.

Financial Services Incumbents	Investment and Wealth Management	Payments	Capital Markets	Digital Infrastructure	Data	Insurance
GDP_Capita	-1.26	2.70*	1.41	0.04	0.40	-1.91^
	(-1.22)	(2.39)	(1.26)	(0.03)	(0.28)	(-1.65)
RI_Cap	1.31**	1.06*	0.91^	0.56	1.16*	0.36
	(2.59)	(2.07)	(1.80)	(1.17)	(2.14)	(0.56)
RD_GDP	-6.57***	-5.802*	-3.65*	-3.18*	-0.34	-1.66
	(-3.34)	(-3.04)	(-2.41)	(-2.00)	(-0.19)	(-1.15)
Lack_of_Trust	-0.49	0.75	-0.91	-0.83	-3.71**	6.48*
	(-0.39)	(0.99)	(-1.04)	(-1.06)	(-2.69)	(2.15)
Broadband_Subs	0.30	6.06**	0.48	1.99	-2.80	-0.80
	(0.17)	(2.93)	(0.33)	(1.04)	(-1.27)	(-0.12)
Mobile_Ph_Subs	6.48*	1.37	1.25	1.74	1.16	-1.97
	(2.26)	(0.54)	(0.59)	(0.59)	(0.26)	(-0.83)
Reg_Inv_Bank_Activity	0.13	0.14	0.29**	0.40***	0.33**	-0.16
	(1.44)	(1.38)	(3.11)	(4.72)	(2.61)	(-1.10)
Country_Inv_Banking_Demand	1.61***	0.70*	0.67*	0.56	0.04	-0.81
	(3.57)	(2.28)	(2.34)	(1.61)	(0.06)	(-1.47)
Retail_Deposits	0.08	0.49	0.10	0.05	1.32	4.33***
	(0.29)	(1.14)	(0.78)	(0.27)	(0.81)	(3.57)
Retail_Fin_Spending	1.79**	3.20*	1.89	2.13^	1.32	12.40***
	(2.66)	(2.04)	(1.46)	(1.86)	(0.67)	(5.24)
Retail_Ins_Spending	4.64***	0.36	0.47	0.88	-0.61	2.14^
	(5.72)	(0.26)	(0.46)	(0.67)	(-0.55)	(1.82)
Prod_Fin_Insurance	1.13	-0.21	0.16	0.16	-0.35	2.90**
	(1.64)	(-0.29)	(0.29)	(0.23)	(-0.33)	(3.26)
Prod_IT	3.17***	0.93	1.02	1.69^	2.07*	3.27**
	(3.72)	(1.10)	(1.49)	(1.73)	(2.20)	(3.21)
AIC	538.54	813.42	978.07	1104.49	488.51	316.20
BIC	681.61	956.50	1121.14	1247.57	631.59	459.28
Log Likelihood	-244.27	-381.71	-464.04	-527.25	-219.26	-133.10

***p < 0.001, **p < 0.01, *p < 0.05, ^p < 0.1. Cluster robust standard errors in parentheses. 2260 Region-Year observations (226 regions over 10 years: 2007 – 2016). Year fixed effects included. The model for the cryptocurrency subsector is not included since incumbents have only 1 patent in cryptocurrencies over the 10 year period.

6.5 Conclusions and implications

What are the factors that influence fintech start-up emergence? What prompts financial services incumbents to innovate? Our study provides evidence from 21 countries and 226 regions on different factors affecting fintech innovation by start-ups and financial services incumbents.

The study contributes to the literature by being one of the first to document the effects of regional knowledge spillovers on fintech entrepreneurship, from two different knowledge sources: the incumbent IT sector vs. the incumbent financial sector. We also analyse the factors influencing fintech innovations in the incumbent financial sector, which is an addition to the study of Haddad and Hornuf (2018) and a significant geographical sample expansion compared to the US study of Chen et al. (2018).

We find that overall, the emergence of fintech entrepreneurship across regions is strongly related to regional knowledge in the IT sector and not the regional knowledge of the incumbent financial sector. The exceptions to this are capital markets applications related to the back-office functions of financial organisations: in this case, fintech start-ups emerge in regions that are also endowed with significant financial sector-related knowledge.

The innovation activities of financial services incumbents tend to occur in regions and countries where they already have developed markets for their services and are not related to the productivity of either the regional IT or financial services sector. This confirms part of Christensen's (1997) disruptive innovation theory, which predicts that the innovation endeavours of incumbents are constrained by their existing customer base, and their pursuit of profitability will drive them to focus on profitable clients, rather than competing with fintech start-ups in delivering services to low margin, underserved clients. The competitive landscape is much more diverse however, if we also consider the

initiatives of established technology players. One such example is the partnership between Amazon UK and Hitachi Capital, which enables consumers to purchase high-value items on Amazon through loan financing offered by Hitachi. The financial risk is born fully by Hitachi, while the loan application is seamlessly done through Amazon (Wack, 2016). In the future, many e-commerce giants can either help enhance the credit risk process of financial services incumbents given the consumer purchasing datasets they have access to or then can chose to compete directly and bear the financial risk themselves. One example of direct competition can be seen in China, where both Tencent and Alibaba are experimenting with their own retail credit rating systems. However, their efforts have been met with resistance from Chinese regulators, given that the government has introduced its own credit risk scoring system (Nonninger, 2018).

The potential implications of our findings for entrepreneurs are manifold. Given that fintech venture emergence is related to the strength of and knowledge created in the regional IT sector rather than the financial sector, the question is whether these start-ups can effectively incorporate financial sector specific knowledge in their products, and whether they can recruit people with financial expertise that would also fit the IT start-up culture rather than the traditional financial services culture. The other strategic implication for entrepreneurs is to realise which business model and fintech sub-segment is likely to benefit from direct competition or collaboration with the incumbent financial sector. Furthermore, as there are a significant number of fintech start-ups which work on data, capital markets and digital infrastructure solutions to improve the incumbent financial sector, many incumbents would be the clients of fintech start-ups rather than their competitors. Scaling some of these start-ups can be also challenging (Bachher et al., 2014) , given the capital required to attract a critical mass of investors and borrowers, as it is the case of lending and investing platforms.

Regulation in the fintech space is likely to require different approaches compared to traditional regulation of financial institutions. Given that fintech innovation is interwoven between technology start-ups, financial sector incumbents and technology incumbents, fintech regulation should be shaped in broad alignment with regulation of the technology sector. Regulation is also likely to take different avenues depending on whether fintech companies are seen as technology companies serving the financial sector or whether they are considered financial institutions falling under financial regulation. The way fintech companies should be classified is yet to be established as the following examples illustrate. Funding Circle, the UK peer-to-peer lending platform that went public on the London Stock Exchange on the 28th of September is classified as a software company under the ICB industry classification promoted by the exchange(London Stock Exchange, 2018). PayPal, a more established payments fintech player, is classified as a financial administration company by ICB, whereas under the GICS classification it is an IT company providing data processing & outsourced services.[27]

Our study is not without its limitations. In studying knowledge spillovers, we use patents as a measure of knowledge generated in the financial sector as well as in the IT sector. The weakness of these measures is that it does not cover all innovations in the sector, as not all innovations are patented, particularly in the financial sector. Although we provide evidence from 21 countries and 226 regions, our data does not include China given lack of access to regional statistics. The developments in China have since 2015 been very significant in terms of fintech investment, overtaking investment in the sector in the US Last but not least, we leave it to future research to analyse the fintech innovation determinants in technology incumbent companies, which would provide a more robust coverage of the fintech innovation landscape.

[27] Source: Bloomberg terminal as of 30 October 2018.

Chapter 6 Appendices

Appendix A.6.1: Fintech company identification and classification process.

To create our universe of fintech start-ups, we conducted two searches on the Crunchbase platform. First, we found all firms with any of the following keywords in the description of their activity: Fintech, Bitcoin, Cryptocurrency, InsurTech, Mobile Payments, Funding Platform, Crowdfunding, Trading Platform. In addition, we found all firms whose activity description included a combination of at least one of the keywords Financial Services, Finance, Banking, Insurance, Payments, Personal Finance, Wealth Management, Stock Exchanges, Credit Cards, Lending, Auto Insurance, Transaction Processing, Compliance, Health Insurance, Micro, Lending, Debt Collections, Debit Cards, Prediction Markets, Life Insurance, Commercial Insurance, Property Insurance, Consumer Lending, with at least one of the keywords: Software Information Technology, Enterprise Software, SaaS, Big Data, Cloud Computing, Internet of Things, Artificial Intelligence, Machine Learning, Predictive Analytics, Cloud Infrastructure, Software Engineering, Data Mining, PaaS, Natural Language Processing and IaaS. The list of companies obtained thus is merged with the CBInsights Fintech 250 List.

Next, we shortlist only those companies from our target 21 OECD countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, United Kingdom, United States. Each company is then mapped to the 226 regions across the 21 countries using a mapping tool provided by the OECD. The final company list is comprised of 3807 fintech ventures which were founded between 2007 – 2016 across the 21 countries above.

Appendix A.6.2: Fintech sub-sector classification.

The types of financial products and services that would fall under the fintech umbrella are numerous, and there is currently no comprehensive taxonomy to analyse the sector. Hence, we provide below a guiding taxonomy for the fintech sector which emerged from our research of numerous articles, reports and market maps (Amalia, 2016; BNY Mellon, 2015; CBInsights, 2017; Deloitte, 2017; EY, 2016; Haddad and Hornuf, 2018; Levy, 2015). We use this classification to categorise both start-ups that provide new technology enabled solutions in the financial sector as well as incumbent patents which describe the integration of more sophisticated IT tools and infrastructure in financial products.

Fintech category	Fintech sub-sector
Investment and Wealth Management	Robo-advisors Portfolio management and analytics Lending and investing platform
Capital Markets	Exchange / trading platform Clearance and settlement technology Risk monitoring Compliance and regulation (RegTech) Fraud detection Debt collection
Payments	Mobile payments Money transfer Payment infrastructure Digital wallets
Cryptocurrencies	Cryptocurrency mining Cryptocurrency exchange
Digital Infrastructure	Blockchain infrastructure Security infrastructure Identity verification API connectivity infrastructure
Data	Business intelligence Alternative Data Provider Business finance, HR and expense reporting and analytics
Insurance	Life insurance General insurance (Re)insurance software analytics Peer-to-peer insurance

Appendix A.6.3: Variable description.

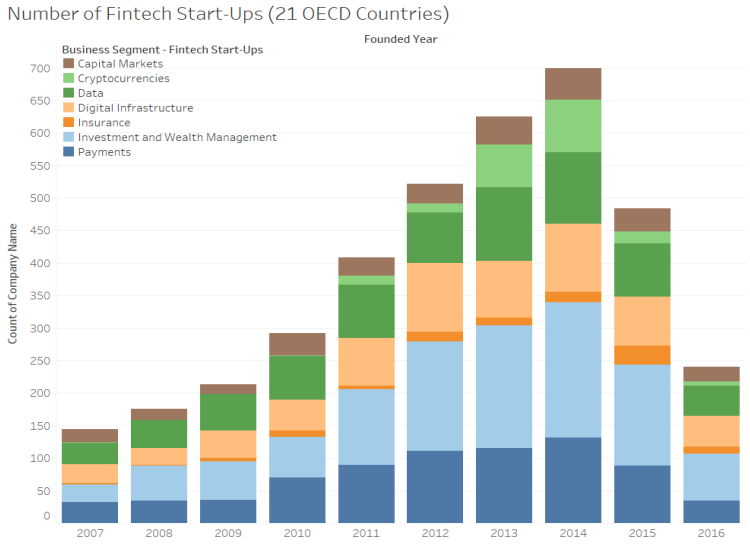
Variable Name	Variable Description	Data source
Fintech_Start-Ups	Count of new fintech ventures per region per year. (2007 – 2016)	Crunchbase, CBInsights.
Incumbent Fintech Innovation	Fractional count of new regional patents in fintech incumbents. Top 400 asset managers (Towers Watson), Top 2000 commercial and investment banks (Dealogic) & Top 776 listed insurance companies (Sustainability Accounting Standards Board) and 186 stock exchanges (Thomson Reuters Datastream).	PatSeer.
IT Knowledge	Regional new IT patent counts per year. (2006 – 2013)	OECD REGPAT Database.
Prod_Fin_Ins	Regional productivity of the financial and insurance sector calculated as GVA per worker.	OECD iLibrary – Regional Statistics and Eurostat
Prod_IT_Coms	Regional productivity of the IT and communications sector calculated as GVA per worker.	OECD iLibrary – Regional Statistics and Eurostat.
Reg_Inv_Bank_Activity	Total fees ($m) earned by investment banks and their subsidiaries on IPOs, bond issuance, syndicated loans and M&As. Regional fees are calculated based on the location of the subsidiaries of investment banks involved in individual deals.	Dealogic
Inv_Banking_Demand	Corporate demand of investment banking services by country ($m fees annually of investment banks by location of investment bank clients).	Dealogic
Retail_Deposits	Annual country level bank deposits in billion $.	S&P Capital IQ.
Retail_Fin_Spending	Retail financial services spending as a percentage of income. Average country level figure (excluding insurance)	Oxford Economics.
Retail_Ins_Spending	Retail insurance spending as a percentage of income. Average country level figure.	Oxford Economics.
Start_Up_Funding	Total regional equity and debt investments ($m) into high-growth start-ups.	Crunchbase
GDP_Capita	Regional GDP / capita	OECD iLibrary – Regional Statistics and Eurostat.
RI_Cap	Number of regional R&D institutions per capita per region in a given year.	GRID
RD_GDP	R&D as % of GDP – annual country figure.	Passport Monitor.
Lack_of_Trust	Percentage of people answering "No" to the question: "In this country, do you trust financial institutions or banks?" – yearly survey.	Gallup World Poll cross country data.
Broadband_Subs	Fixed broadband Internet subscriptions/100 people.	World Economic Forum Global Competitiveness Index.
Mobile_Ph_Subs	Mobile telephone subscriptions/100 people.	World Economic Forum Global Competitiveness Index.

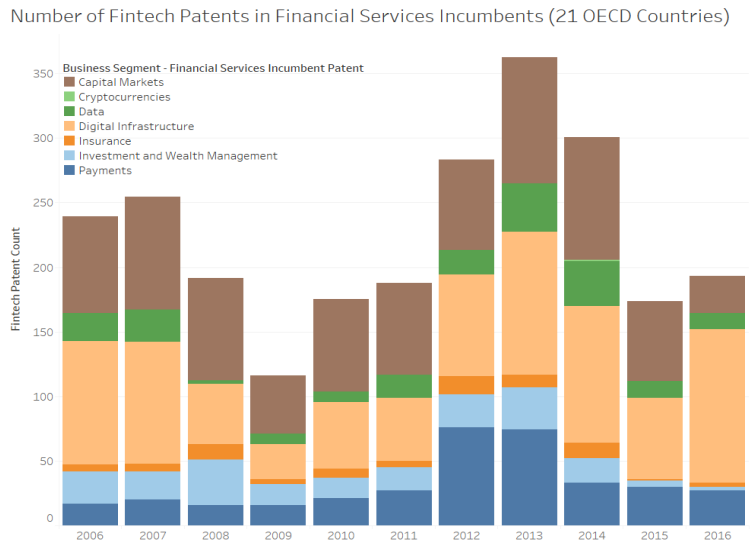
Appendix A.6.4: Fintech start-ups descriptive statistics

The emergence of fintech start-ups across our 21 OECD countries has surged from 144 start-ups in 2007 to 699 new fintech ventures in 2014. This was followed by a drop in new fintech ventures post 2014, which is in line with the drop in new high-tech start-ups across the world documented in Chapter 4, partly due to private companies staying private for longer and many early stage investors moving towards later stage investment opportunities. In addition, some investment has shifted to China, which in 2016 boasted c. $7.7 billion in fintech start-ups compared to $6.2 billion across the US and just $2.2 billion across Europe in the same year (Wójcik and Cojoianu, 2018a).

The fintech sub-sectors that have grown most in the start-up world are investment and wealth management solutions (e.g. robo-advisors) and payments. This is also reflected in the overall funding levels, as much of the funding was used to capitalise the many lending platforms that emerged. The rise of cryptocurrencies can be observed post-2011 as a focus for start-ups, although little or no innovation efforts seem to have been placed on this sub-sector by financial sector incumbents. Approximately 70% of fintech start-ups (out of 3,807) are in the US, followed by the UK with c. 17% (563) and Canada with 4.8% (185). The regions that fostered over 100 start-ups over the period are California, London, New York and Texas with 841, 458, 446 and 101 start-ups respectively.

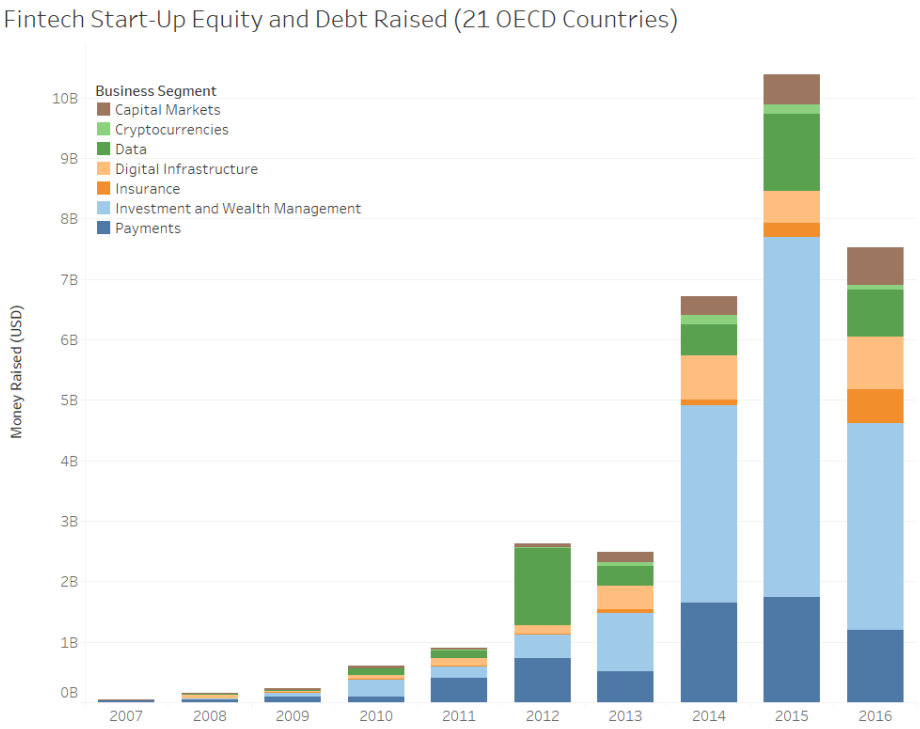
Fintech start-up emergence and fintech innovation in financial services incumbents.





Appendix A.6.4 (Continued)

Fintech start-up equity and debt investment across fintech categories.



We identify 2,280 fintech-related patents in the incumbent financial sector, which are overwhelmingly filed from the US (over 73%). At the regional level, within the US, the states with most incumbent patenting activity in fintech are New York, New Jersey and California with 1,148, 100 and 79 patents respectively. Outside the US, London takes the lead with 286 fintech patents, followed by Quebec (92), Scotland and Stockholm (each with 43 fintech patents). In the US, the geography of fintech incumbent innovation seems closely related to the geography of mid and back offices where states like North Carolina are likely to have benefited from bank optimising their value chains post crisis (Wójcik and Cojoianu, 2018b). The areas in which financial services incumbents innovate are closely related to their core activity and capabilities, namely investing in capital markets solutions (including clearance and settlement solutions, risk monitoring and compliance and regulation) and digital infrastructure (e.g. security infrastructure, identity verification and digital connectivity infrastructure).

Appendix A.6.4 (Continued)

Fintech start-ups and financial services incumbent patents across our 21 countries. Period: 2007 – 2016.

Start-Ups by Country

Country	
United States	2,382
United Kingdom	563
Canada	185
Germany	130
Spain	112
Australia	90
Netherlands	59
Ireland	54
Italy	42
Denmark	37
Sweden	35
Belgium	25
Finland	24
Poland	16
Austria	14
Czech Republic	12
Norway	11
Greece	5
Hungary	4
Portugal	4
Slovak Republic	3

Start-Up US States

Region	
California	841
New York	446
Texas	101
Massachusetts	96
Florida	95
Illinois	95
Washington	74
Georgia	66
Colorado	48
New Jersey	45
Pennsylvania	40
Virginia	39
North Carolina	37
Michigan	36
District of Columbia	33
Ohio	26
Nevada	23
Arizona	21
Oregon	21
Utah	19
Tennessee	18
Missouri	17
Connecticut	15
Minnesota	14
Delaware	13
Indiana	11
Kentucky	10
Maryland	10

Start-Up Non-US Regions

Region	
Greater London	458
Ontario	96
Berlin	56
West-Nederland	55
British Columbia	54
New South Wales	53
Southern and Eastern	52
Madrid	44
Catalonia	35
South East England	32
Capital (DK)	30
Lombardy	26
Stockholm	26
Bavaria	25
Victoria	22
Helsinki-Uusimaa	19
North West England	17
Quebec	17
East of England	15
Flemish Region (Vlaams Gewest)	14
North Rhine-Westphalia	14
Alberta	12
Hesse	11
Andalusia	10
Hamburg	10
South West England	10

Incumbent Patents by Country

Country	
United States	1,674
United Kingdom	375
Canada	100
Australia	45
Sweden	43
Italy	24
Netherlands	7
Spain	7
Germany	3
Hungary	1
Ireland	1
Austria	0
Belgium	0
Czech Republic	0
Denmark	0
Finland	0
Greece	0
Norway	0
Poland	0
Portugal	0
Slovak Republic	0

Incumbent Patents US States

Region	
New York	1,148
New Jersey	100
California	79
Pennsylvania	65
North Carolina	53
Minnesota	30
Delaware	25
Connecticut	18
Illinois	17
Massachusetts	17
Ohio	16
Rhode Island	16
Maryland	15
Tennessee	13
Washington	10
Florida	7
Vermont	7
Virginia	7
Georgia	6
Iowa	5
Texas	4
Arizona	2
Colorado	2
Michigan	2
New Hampshire	2
South Dakota	2
Utah	2
Alabama	1
Montana	1
Oregon	1
South Carolina	1

Incumbent Patents Non-US Regions

Region	
Greater London	286
Quebec	92
Scotland	43
Stockholm	43
New South Wales	24
Victoria	21
Lazio	17
South East England	15
North West England	13
East Midlands	8
East of England	7
Madrid	7
Ontario	7
West-Nederland	7
Lombardy	4
North Rhine-Westphalia	3
Piedmont	2
British Columbia	1
Central Hungary	1
South West England	1
Southern and Eastern	1
Tuscany	1
Wales	1
Yorkshire and The Humber	1

We only display US states and non-US regions with more than 10 start-ups. In the case of incumbent patents originating in the US we only display those states with more than 10 patents, while for incumbent patents originating outside the US we display those regions 1 or more patents

Appendix A.6.5: Correlation matrices.

a. Correlation matrix for models over 2007 -2016.

Variable Name	Mean	Sd.	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]
[1] Lack_of_Trust	0.47	0.17															
[2] Start_Up_Funding	236.27	1799.6	0.01														
[3] GDP_Capita	37826.37	15407.83	-0.14***	0.14***													
[4] RI_Cap	5.16	7.22	-0.29***	0.03	0.23***												
[5] Prod_FIN_INS	112.84	58.61	-0.03	0.01	0.33***	0.28***											
[6] Prod_IT_Coms	114.05	52.88	0.21***	0.32***	0.53***	0.10***	0.35***										
[7] Reg_Inv_Bank_Activity	770.84	5220.25	-0.02	0.00	0.11***	0.03	0.00	0.11***									
[8] Country_Inv_Banking_Demand	13614.97	22923.25	-0.10***	0.19***	0.44***	0.02	-0.12***	0.50***	0.22***								
[9] RD_GDP	1.97	0.80	-0.23***	0.11***	0.49***	0.09***	0.04	0.34***	0.11***	0.48***							
[10] Broadband_Subs	23.03	8.29	0.14***	0.07**	0.29***	0.15***	0.23***	0.22***	0.03	0.09***	0.55***						
[11] Mobile_Ph_Subs	110.92	23.38	0.44***	-0.08***	-0.23***	-0.08***	0.04	-0.16***	-0.12***	-0.52***	-0.15***	0.16***					
[12] Retail_Deposits	2400.29	3232.68	0.27***	0.16***	0.35***	-0.07***	-0.24***	0.44***	0.16***	0.66***	0.42***	0.40***	-0.19***				
[13] Retail_Fin_Spending	0.02	0.01	-0.38***	0.10***	0.17***	0.07***	-0.34***	-0.01	0.13***	0.53***	0.25***	0.14***	-0.52***	0.34***			
[14] Retail_Ins_Spending	0.02	0.01	-0.32***	0.02	0.22***	0.05*	0.06**	-0.10***	0.03	0.10***	0.18***	0.25***	-0.45***	0.08***	0.25***		
[15] Fintech _Start_Ups	1.68	8.22	0.05*	0.72***	0.20***	0.05*	0.04*	0.37***	0.05*	0.19***	0.11***	0.11***	-0.08***	0.22***	0.13***	0.04*	
[16] Fintech_Incumbent_Innovation	1.00	8.58	0.00	0.19***	0.14***	0.04	0.13***	0.27***	0.03	0.15***	0.07***	0.04*	-0.07***	0.14***	0.10***	0.03	0.51***

Pearson correlation coefficients. ***p < 0.001, **p < 0.01, *p < 0.05, ^p < 0.1

b. Correlation matrix for models testing the knowledge spillover of entrepreneurship over 2007 -2014.

Variable Name	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]
[1] Lack_of_Trust																
[2] Start_Up_Funding	0.02															
[3] GDP_Capita	-0.11***	0.15***														
[4] RI_Cap	-0.26***	0.03	0.23***													
[5] Prod_FIN_INS	-0.02	0.00	0.32***	0.24***												
[6] Prod_IT_Coms	0.24***	0.33***	0.52***	0.10***	0.36***											
[7] Reg_Inv_Bank_Activity	-0.02	0.00	0.10***	0.03	-0.01	0.12***										
[8] Country_Inv_Banking_Demand	-0.09***	0.21***	0.43***	0.02	-0.13***	0.49***	0.22***									
[9] RD_GDP	-0.20***	0.12***	0.49***	0.09***	0.02	0.32***	0.11***	0.48***								
[10] Broadband_Subs	0.15***	0.07**	0.30***	0.15***	0.22***	0.23***	0.03	0.10***	0.58***							
[11] Mobile_Ph_Subs	0.46***	-0.10***	-0.22***	-0.07**	0.06*	-0.10***	-0.12***	-0.52***	-0.15***	0.19***						
[12] Retail_Deposits	0.31***	0.17***	0.33***	-0.07**	-0.25***	0.43***	0.16***	0.66***	0.41***	0.39***	-0.14***					
[13] Retail_Fin_Spending	-0.35***	0.13***	0.18***	0.08***	-0.33***	0.01	0.13***	0.56***	0.28***	0.16***	-0.57***	0.35***				
[14] Retail_Ins_Spending	-0.31***	0.03	0.22***	0.06*	0.06*	-0.10***	0.04	0.11***	0.21***	0.26***	-0.47***	0.07**	0.26***			
[15] Fintech _Start_Ups	0.07**	0.84***	0.19***	0.05*	0.05*	0.37***	0.05*	0.19***	0.12***	0.12***	-0.07**	0.23***	0.13***	0.04		
[16] Regional Fin. Serv. Incumbent Knowledge	0.00	0.23***	0.15***	0.04	0.14***	0.27***	0.03	0.16***	0.08**	0.04	-0.07**	0.15***	0.10***	0.02	0.50***	
[17] Regional IT Knowledge	-0.03	0.85***	0.21***	0.05*	0.00	0.32***	0.04	0.21***	0.21***	0.10***	-0.12***	0.18***	0.11***	0.07**	0.69***	0.15***

Note: Start-up funding is orthogonalized with respect to IT sector knowledge given the high correlation between the two variables. Pearson correlation coefficients. ***p < 0.001, **p < 0.01, *p < 0.05, ^p < 0.1.

7 Conclusion

7.1 Introduction

The thesis sets out to explain the rise of environmental investing and financial technologies through the lens of the interactions between and geographical scope of financial intermediaries and their clients. Both environmental finance and fintech have emerged in response to the overarching theme and need to realign the financial sector with societal interests. Climate change, as a global problem, has attracted the attention of investors through its present and anticipated impacts on economic activity around the world, becoming a financially material risk for intermediaries across the investment chain. The attention of investors towards climate change has also been further gauged by civil society actors calling them to end the financing towards greenhouse gas emission intensive activities that contribute to global warming. The rapid fall of the cost of green technologies in the past two decades has meant that investors are not only exposed to downside risk from climate change, and more broadly environmental risks, but they are also in the position to profit from the low carbon transition. However, the progress on halting GHG emissions worldwide has been slow and both governments and financial institutions around the world still support the building of fossil fuel infrastructure that would take the world beyond the 2°C warming threshold (Pfeiffer et al., 2018; UN, 2018).

The rise of new financial technologies is largely due to the global financial crisis, which unveiled a global financial sector which is preoccupied with serving itself rather than the economy that it underpins. The all-time low trust levels in financial intermediaries and the recognition from technology circles that IT innovations could be the key in creating more efficient, transparent and customer centric financial services,

paved the way for the emergence of crowdfunding platforms, crypto currencies and low-cost money transfer services amongst other (Wójcik and Cojoianu, 2018a).

The striking common feature between environmental finance innovations and financial technologies, is not necessarily that both movements claim to better align the financial sector with society, but rather, that they are both partly built upon the incumbent technology and financial infrastructure and as importantly, on the existing social ties and networks of individuals and organizations which have distinctive and dynamic geographical characteristics (Arner et al., 2016; Knox-Hayes, 2009). What is more, particularly in the case of environmental investing, the issues that these movements are trying to solve have an inherent uneven geography. Hence, explaining the interaction and tension between the geography of finance (Clark, 2017; Lee et al., 2009) and the geography of innovation (Audretsch and Feldman, 2004; Feldman, 1994) in the context of environmental investing and financial technologies is the key way in which this thesis seeks to explain these two trends. In doing so, I also linked the geography of finance and geography of innovation literatures with the fields of environmental policy and sustainable investing, to provide complementary insights into the geographical scope of financial intermediaries and their clients.

In this concluding chapter, I reiterate the main findings of the thesis and interpret them in a broader context. I highlight how each of the four substantive chapters have contributed to the literature and illustrate the implications for the study of financial intermediation and its impact on society. Last but not least, I will illustrate potentially prolific research avenues which to a certain degree will address the limitations of this study and will advance our understanding of the intersection between finance, technology and the environment.

7.2 Thesis findings and contributions to literature

In the introduction, the thesis sets out to argue that financial markets are critical in delivering the future low carbon economy and in appropriately responding to climate change at the global level (Knight, 2010). However, I also outline how the financial sector is part of the problem given that historically it failed to take into consideration environmental, social and governance considerations in asset allocation decision-making and moreover, given that its innovation activities were self-serving and ultimately damaging for their customers and their own reputations as the global financial crisis has shown. I then argue that understanding the rise of environmental investing and financial technologies, or in other words the finance – technology – environment nexus, requires an exploration of the relationships between financial intermediaries and their clients and the geographical scale at which these dynamics play out.

The first important contribution of the thesis to the economic geography literature is in unveiling the global map and country level fundraising amounts in the oil and gas sector. This really emphasises the global scope of the financial sector, but also that of the oil and gas sector. The thesis then shows in a first-of-a-kind study across asset classes that fossil fuel divestment commitments have negatively affected the total financing amount in the oil and gas sector, particularly when these commitments are made by government or government-backed organisations. These findings contribute to the limited quantitative evidence on the effects of the fossil fuel divestment campaign, but not only expanding the research across asset classes but also across the world. Next, I show that the increasing stringency of emissions trading schemes is also negatively impacting oil and gas fundraising. I also document the limits of both environment policy and anti-fossil fuel norms, by showing that a bank's home country environmental policy or divestment commitments do not influence whether a bank exports financial services to

foreign oil and gas companies. The study is an original addition to the environmental economics literature on the connection between environmental policy and competitiveness, by linking the financing of the oil and gas sector with environmental policy stringency.

To further illustrate the link between green investment, environmental policy and economic phenomena which are better captured in a regional, rather than country level context, the thesis shifts its focus from the global oil and gas sector to regional entrepreneurship. In this context, I find that a more stringent environmental policy regime is negatively related with the creation of new fossil fuel ventures, which was expected. Unintuitively however, the same is true for the creation of new green ventures, which suggests that environmental policy, although more stringent, fails to create more opportunities for entrepreneurs. The emergence of green start-ups is highly concentrated in regions with high availability of venture capital financing, but as importantly, in regions where new environment-related knowledge is created. The thesis shows that new knowledge is the source of entrepreneurial opportunity in most industries, and the green sector is no exception. The study also illustrates that it is unlikely that new fossil fuel related ventures are formed in regions with high environmental knowledge outputs, which is in alignment with the hypothesis that it is unlikely that entrepreneurs are seeking to "green" the fossil fuel sector. The study tests in parallel hypotheses from the fields of innovation studies (Acs et al., 2009; Audretsch and Keilbach, 2007b) and environmental economics (Ambec et al., 2013; Calel and Dechezleprêtre, 2016) across 24 OECD countries and provides evidence across the most robust coverage of the regional green entrepreneurship phenomena to date.

Having provided insights at the global, country and regional level on environmental investing and green technologies, the thesis then takes the perspective of a lender that is

exposed to natural capital and environmental risks through its investments in farming enterprises that have significant impacts and dependencies on natural capital. In this example, the lender has a national or regional investment focus, while the environmental risk for their clients can be local, regional, national or even global in nature. This part goes to the heart of environmental finance, complementing the top down approach of Zeidan, Boechat and Fleury (2015) by developing a bottom up, robust evidence base on the ways different natural capital risks and dependencies are likely to impact the financial performance of wheat farms in Australia. The study also shows how these risks can be mitigated against, and ultimately how these risks can be assessed by lending institutions. I find that the advancement in sensor technology now allows for the quantification of environmental risks at the farm / asset level at an adequate frequency to be useful for credit risk assessments. That being said, although quantitative indicators of risk exposure are useful, the credit risk assessment would not be complete without qualitative input on the knowledge and management practices of farmers regarding these risks.

From a quantitative perspective, some risks are less challenging to evaluate than others. For example, energy use and greenhouse gas emissions are relatively easy to monitor and to price. Furthermore, most financial institutions are inclusively aware of climate change risks. At the other end of the spectrum, soil health risk factors are highly complex, interconnected and manifest themselves in the long term, which makes them challenging to grapple with. This paper came to light from the need to provide some early evidence into the relationship between environmental sustainability and finance for small to medium sized loans in industries where producers are numerous and highly dispersed, and where they depend on natural capital as a main input to their business models. This is the case of agriculture, where so far, the scaling up of environmental risk data services has been hard to scale across many farms. The study's main contribution is

to the literature focused on banking and the environment (Georgopoulou et al., 2015; Nandy and Lodh, 2012; Weber, 2012; Weber et al., 2015). Its innovativeness lies not only in the novel findings, but also in the generalisability of the research method across agricultural sub-sectors, countries and regions.

Finally, by furthering the theme of the inseparable link between finance and technology, the thesis shows that financial technology start-up creation is positively related to regional knowledge created in the IT sector and unrelated to regional knowledge in the incumbent financial sector. On the other hand, fintech innovation by financial services incumbents occurs in regions and countries where the clients and high fee earning subsidiaries of incumbents are located, while regional IT or financial sector productivity do not seem to be important for it. This finding, together with the exploratory analysis of the types of technologies created by financial services as opposed to fintech start-ups, point towards Christensen's (1997) model of disruptive innovation, where incumbents pursue high revenue clients and improve on their existing infrastructure, whereas start-ups pursue low margin and underserved clients, including retail clients and SMEs, with more cost-effective solutions. This paper’s contributions are to the emerging literature on financial technologies (Arner et al., 2016; Chen et al., 2018; Haddad and Hornuf, 2018), but also to entrepreneurship and innovation literature (Audretsch, 1995; Delgado et al., 2010; Feldman, 1994). It is the first account of fintech innovation emergence at the regional level and the first time the knowledge spillover of entrepreneurship is tested in this industry context.

7.3 Implications for future research

In this final section, I suggest implications for future research by drawing on the findings and limitations of each substantial chapter. In addition, I will also comment on

broader questions on finance and sustainability and how these could be addressed in future research projects.

The implications of the present thesis are numerous. Beyond its application to economic geography, the findings imply that the field of financial economics would greatly benefit from a wider consideration of geographical heterogeneity in its effort to explain the mechanisms of financial intermediation. As far as the efficient market hypothesis is concerned, the study shows that there are many commercially relevant environmental datasets, that are hard to get to and also challenging to analyze at the geographical scale at which they manifest (e.g. environmental risks in lending in Chapter 5). This means that few geographically contextual environmental risks are incorporated in the decision-making process of financial intermediaries (Cojoianu *et al.*, 2015), hence there are significant opportunities for intermediaries with the knowledge and technical expertise to acquire, analyze and act upon such information.

While both Chapters 3 and 5 provide evidence regarding the lending activities of banks in the oil and gas and agricultural sectors, the thesis was not able to quantify the extent to which the cost of capital of oil and gas companies is affected by increasing environmental policies and fossil fuel divestment commitments and equally, it was not able to analyse the cost of capital incurred by farms exposed to natural capital risks. Hence, a prolific research avenue is that of analysing the effect of environmental risks on the cost of capital across industries and across different geographical scales. This would allow for a better understanding of how environmental risks translate in capital market outcomes outside the equity secondary market which has been the focus of many academic studies.

The thesis has only scratched the surface of the impact of anti-fossil fuel norms on economic and financial outcomes (Chapter 3). Additional questions to be addressed

include: whether fossil fuel divestment pledges result in more investment in the green economy, and if so, on which asset classes and geographies; whether cities and regions which have pledged to divest from fossil fuels are more successful in transitioning to a low carbon economy than those who haven't and last but not least, whether national fossil fuel divestment pledges influences the rate of adoption and assets invested in fossil fuel free financial products. The literature would also benefit from further clarification on the decision-making processes of financial intermediaries, and what determines the choice of divestment, as opposed to, for example, engaging with the oil and gas sector. A potential causal test for the impact of divestment commitments on fossil fuel fundraising can be further conducted at the company level, using a difference-in-difference research setting where the cost of capital and fundraising amounts of oil and gas companies located in countries with strong divestment commitments are compared with those of companies located in countries with very weak or no fossil fuel divestment commitments.

As Hepburn (2010) observes, the design of environmental policy is likely to be influenced more by the political economy of states and companies than environmental economic theory. Zietsma, Ruebottom and Slade Shantz (2018) and Carroll *et al.* (2018) further note that the fossil fuel sector exerts significant influence on the policy making process and that there are numerous conflicts of interests that act as a soft climate change denial regime, which ultimately are a barrier to the rapid low carbon transition. As Chapter 3 has shown, environmental entrepreneurship emergence is negatively related to environmental policy stringency. Future studies could address whether environmental policy truly encourages the success of low carbon business models, or whether its slowly paced stringency increase is due to the influence of fossil fuel incumbents. Another aspect which Chapter 3 has engaged with is that of state intervention in environmental financial markets through the actions of government backed financial institutions. Future

research would benefit from analysing how the forms and functions of sovereign wealth funds across the world impact the scope and choice of green investment strategies that they employ. Furthermore, the literature would benefit from a clarification on how central banks and financial supervisors influence the adoption of environmental risk assessments across the banking sector.

Chapters 4 and 6 explore the factors which are likely to influence entrepreneurship in the context of the low carbon transition and financial technology transformation. Both chapters illustrate the role of new and commercially relevant knowledge in new venture formation and how entrepreneurs rely on existing technology clusters for the infrastructure supporting new technologies and business models. Hence, is it realistic to expect that these start-ups will be able to address some of the broader issues of uneven development, access to clean energy and access to finance? More research is needed to establish whether and how the location choice of green and fintech entrepreneurs affects sustainable development outcomes across geographies. Furthermore, it would be beneficial for both the academic literature and industry practice to understand how these entrepreneurs interact with incumbents through alliances, direct competition or supply chain relationships and how change towards a low carbon and more sustainable financial system occurs. In the case of environmental entrepreneurship, testing the impact of environmental policy that would allow for causal inferene can be done by comparing sudden changes in environmental legislation in a given country (e.g. UK) and whether this impacts green entrepreneurship as compared to green entrepreneurship in a country which did not experience such shock and has comparable environmental policy implementation (e.g. Ireland). For fintech entrepreneurship, expanding on the relationship between technological capability, trust in financial services and fintech entrepreneurship and innovation outcomes, it is possible to conduct a study using the

financial crisis as an exogenous shock and study fintech entrepreneurship outcomes in a quasi-natural-experiment research framework.

Chapter 5 unveils that there is little that we know about the material environmental risks across different timeframes and geographies of highly fragmented industries, composed of many small or medium-sized enterprises whose main source of external finance are small scale loans. Further research would be welcome in addressing this literature gap. At the moment, several studies would need to be conducted to validate correlations between natural capital risks and financial performance at the farm level or portfolio of loans level. Causality could be perhaps inferred by studying whether and how banks adjust their medium-long term interest rates in response to unexpected weather events which impact the agricultural sector.

Finally, I would like to conclude with two important points about future research. The first point is related to the thesis finding that fossil fuel financing has increased significantly over the 2000 – 2015 period, in spite of increased claims from financial institutions and fossil fuel companies that they are actively looking for climate mitigation solutions. Research into greenwashing is still in its infancy, since much attention has been devoted to corporate social responsibility and materiality of environmental, social and governance risks in the investment process. While it is possible that financial intermediaries finance both environmentally sustainable and unsustainable businesses in the low carbon transition, the truthfulness of their claims with respect to the degree that they engage in each will determine our ability to accurately and timely track our progress and efforts towards achieving a net-zero carbon economy. New financial technologies focused on transparency could potentially help with the issue of greenwashing.

The second point has to do with the academic process and how policymakers, financial intermediaries and the business sector can benefit from academic insights in a

timely manner, given the urgency of the need to act on climate change. It is highly unlikely that academics will be able to provide many causal insights on the impacts of climate change, as climate change cannot be reliably predicted from historical datasets. In this sense, taking an approach from medical sciences may be advisable, where climate change is treated as a disease, and in order to treat it, it is advisable to start treatment according to identified risk markers and in parallel research other variables that may be the direct cause for the slow progress towards climate change mitigation (Hoepner, 2016).

7.4 Implications for policy, industry and society

The thesis findings also have wide implications about the debate of whether an adequate price on carbon will likely solve the climate issue. In reality, besides the price signal, contextual knowledge about the environment for financial intermediaries, businesses and ultimately governments is another salient aspect which is often overlooked in climate action discourse. Herein lies the public policy challenge: to foster the diffusion of environment-related knowledge so that it benefits green and financial technology innovations where they are needed most. That being said, lessons from place-based policies which failed in re-creating Silicon Valley across the world still apply in the context of cleantech and fintech. However, there is a distinctive difference between policy and regulation as far as the two industry sectors are concerned. While the innovation trajectory of many clean technology solutions has been incremental and is largely waiting for adequate climate change regulation and participation of the public sector in its broad deployment, financial technologies have been disruptive in nature, with rapid adoption of technologies such as digital wallets, use of crowdfunding platforms and new money transfer services among others. In the case of financial technologies, much of the policy is reactive, grappling with issues of financial regulation,

data privacy and consumer protection among other aspects which need the attention of policymakers.

The research is also relevant to the newly formed UN backed Financial Centres for Sustainability (FC4S) initiative[28] which aims to promote sustainable finance innovation across financial centres all over the world. These innovation activities are likely to be shaped by the geography of environmental technologies within the home countries of the respective financial centres, as well as the expertise across different types of financial organizations in a financial centre which aim to export financial services to other financial centres.

The study illustrated that the state's influence in financial markets, including green financial markets and financial technologies, is also exerted through government backed financial institutions such as central banks, sovereign wealth funds, state-funded venture capital equity and debt funds and municipal pension funds amongst others. Chapter 3 shows that their action can affect outcomes related to the green economy, and not only, as many of these institutions have also taken a keen interest in financial technologies too. Hence, a valuable investment signal for those operating across both cleantech and fintech can be unveiled by following this soft government involvement across different financial institutions, asset classes and geographies. Former UN secretary general, Ban Ki-moon drew attention to this issue recently, when it criticised the UK government for exporting financial services to many fossil fuel projects through its UK Export Finance department, which provides lines of credit and insurance to help companies win business overseas (Vaughan, 2019).

This brings us to the implications and lessons for financing innovation in the 21st century. The investigation of the annually produced Bloomberg New Energy Finance

[28] https://www.fc4s.org/about-us

report in clean technology investment trends unveils that asset (project) finance is the overwhelmingly accepted model for financing renewable energy. This was not clear in the early days of cleantech, when much of the attention and even US government policy was focused on incentivising venture capital financing for entrepreneurs to provide green infrastructure (Gaddy et al., 2017; Hargadon and Kenney, 2012). This led to the failure of many early VC backed green ventures, given the mismatch between venture capital financing and the capital intensiveness inherent in green infrastructure, and a shifting of entrepreneurs towards software solutions for sustainable development, which the VC industry had much experience in financing. This unveils that there is still room for financial innovation to address the mismatch between investment horizon, risk and capital intensiveness of clean energy projects with appropriate sources of patient capital. Chapter 6 has shown that much of the capital that drove the rise of fintech was not channelled necessary in the technology itself, but rather in providing capital for investment, trading and payments on new platform technologies. This means that it is possible that much of the financial innovation needed for green technologies can perhaps emerge from the current fintech innovation wave.

As the thesis dedicates two chapters to green and fintech entrepreneurship, I outline the implications for entrepreneurs. Given the importance of knowledge in the entrepreneurial process, environmental entrepreneurs may be able to enhance their chances of founding successful start-ups by participating in knowledge networks with deep expertise in environmental management. Given that environmental policy stringency has been shown to work against new venture creation, entrepreneurs may enhance their opportunities by being more vocal and active in influencing the alignment of environmental policies with broader technology and entrepreneurship policies (Dean and McMullen, 2007). For financial technology entrepreneurs, who have benefited from

the knowledge embedded in technology clusters, the question remains whether they can design effective financial innovations which directly compete with financial services incumbents or whether there is a broader scope for entrepreneurs to collaborate with incumbents. Geography is again a relevant factor not only for entry in a particular industry, but also in the context of successful scale-ups.

Last but not least, the thesis findings are highly relevant for civil society, campaigners and the NGO sector. As Chapter 3 illustrates, a better understanding of the financial sector as well as of government can inform and enhance the influence that these groups have on the policymaking process as well as on key financial decisions, which are related to societal interests.

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