“Complexities in Inter-firm R&D Collaborative Partnerships in High-Tech Industries: Innovation and Financial Performances”

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To the University of Exeter

As a thesis for the degree of Doctor of Philosophy in Management Studies

April, 2018

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Abstract

Governments in both advanced and emerging markets invest heavily into joint R&D projects to facilitate inter-firm collaboration and scientific productivity. As a science-based cluster, nanotechnology is a highly R&D-intensive field with very complex interdisciplinary features that enables multiple interactions between scientists from diverse cultural backgrounds working for multi-faceted organizations across public and private sectors and through internationally regulated borders. In this thesis, I examine the main determinants of the dimensions of inter-firm collaboration in high-tech industries particularly among nanotechnology R&D organisations across Europe. Also, I investigate the key factors that influence the innovation, financial and exit performance of nanotech companies during the commercialisation period and across 15 developed and developing countries, taking into consideration the involvement of venture capital (VC) firms. In order to methodically integrate the qualitative and quantitative features of my research study, I employed mixed method to analyse primary and secondary data collected via survey instruments and comprehensive databases; to gain valuable insights into the complexities around nanotech R&D organisations.

The regression results show that a predictable legal system; a high level of tolerance for uncertainty; the proximity to key partners; a high level of export demand for high-tech products; and expansionary economic policies, leads to highly valuable and long-term relationships which produces optimal partnership size with an effective organizational structure. I find that a high financial status of nanotech firms equips R&D project managers with sufficient tangible and intangible resources to engage into complex collaborative partnerships which yield innovative performing outcomes. Also, I find that nanotech R&D firms that exit venture capital investments via IPO are more likely to have their head offices in a big city; and access foreign capital to expand manufacturing operations. I conclude that the successful commercialisation of nanotechnology industries across the globe has been due to the substantial R&D public expenditures and private investments into the application and proliferation of nanotechnologies in key converging scientific fields which require robust inter-firm collaborative partnerships to rapidly develop and promote several portfolios of high-tech products that continually satisfy consumer needs in disruptive ways and secure long-term profitability for nanotech R&D organisations.

Acknowledgement

I would love to acknowledge and dedicate this thesis to my personal Lord and Saviour Jesus Christ, who is King of the Jews and the Prince of Peace. In Him I breathe, move and have my being. Life is worthless without Him and through Him all things were made. To my amazing parents who guided me in the way of the Lord, I honour and appreciate you. Also, to my brothers and sisters who greatly supported me in this academic adventure, I will never forget your incredible support. To my supervisors – Dr. Stanley Gyoshev and Professor Nazrul Islam, I am very grateful for your astonishing support and encouragement, without which I wouldn't have been able to complete this thesis.

Also, I would like to appreciate Her Majesty – Queen Elizabeth II, for her Christian value promotion around the world of which my home country Nigeria has benefited greatly. To the most amazing research faculty – Professor Kim Soin, Dr. Rajesh Tharyan, Mrs Helen Bell and Dr. Kate Gannon, I have never seen such support ever before. You all kept my dreams alive, gave me strength to pull through in very difficult times and supported me when all hopes were gone. To my colleagues and friends in the University of Exeter and Rediscover Church, I am humbled by your love and believe in my God given abilities.

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List of Abbreviations

Nanotech - Nanotechnology

VC – Venture Capital

PE – Private Equity

EU – European Commission

BRICS – Brazil, Russia, India, China and South Africa

EMEs – Emerging Market Economies

IPOs – Initial Public Offerings

M&As – Mergers and Acquisitions

GFC – Global Financial Crisis

R&D – Research and Development

NNI – National Nanotechnology Initiatives

FP – Framework Programme

ICT – Information and Communication Technology

NPD- New Products Developed

Chapter 1: Introduction

1.1 Background

Research collaboration in scientific exploration can be developed among individual scientists in interdisciplinary groups; across public/private sectors such as university and industry; and between countries such as multi-national cooperative institutes (Fiaz, 2013; Ponomariov, 2013). Research collaboration is usually peculiar among experimental research due to its interdisciplinary features and the use of large or complex instrumentation such as telescopes and CT scanners (Lee, 1996; Bozeman and Corley, 2004). Governments around the globe have provided resources as well as incentives to promote rapid growth and dissemination of scientific knowledge as a means of facilitating international collaborations; in order to promote indigenous innovation, exploit research synergy, and enhance scientific excellence (Tang and Shapira, 2012).

For instance, the European Commission actively invests into joint R&D projects, in conjunction with the private sector, to facilitate inter-firm collaboration and scientific performance in an attempt to foster global competitiveness (Paier and Scherngell, 2011). A key challenge for European R&D policy makers is to define an optimal collaboration scale for fund mobilization across local, regional, national and international cooperative partnerships to promote a vibrant and prosperous socio-economic environment. Through the Framework Programme (FP) for research funding, the European Commission has vigorously financed inter-firm R&D projects (Roediger-Schluga and Barber, 2006; Paier and Scherngell, 2011) to promote innovative performance in high-tech firms so as to enhance their global competitiveness (Scherngell and Lata, 2013). Globalization of science, technology and commerce has rapidly advanced human endeavour; making it essential for high-tech firms to continually improve their product lines and manufacturing processes to meet the ever-increasing stakeholder expectations (Lo et al., 2011).

Most policy initiatives and organizational strategies are geared towards facilitating collaboration, not only on the level of individual scientists (Wagner and Leydesdorff, 2005), but also on a higher level of inter-firm cooperative engagements (Wong, Ho, and Chan, 2007). The merits of inter-firm collaborations in high technology industries are the diversification of risks in an uncertain environment and the transfer of knowledge among cooperative partners (Park and Kang, 2013). It has been found that organizations that are highly involved in collaborative partnerships enhance their competitiveness, experience greater return on their investment and enjoy a much higher rate of success (Todeva and Knoke, 2005).

As an engine for economic growth, job creation and radical innovation in knowledge -based economies (Protogerou et al., 2017); high-tech firms play an important role in establishing collaborative partnerships with universities (Caloghirou et al., 2001) in order to develop a portfolio of innovative products and pioneering systems (Nieto and Santamaria, 2007) which thrives despite the swift changes in the socio-economic and technological environments (Baranenko, et al., 2014) that requires shorter product life cycles as a result of intense global competition (Deeds, DeCarolis and Coombs, 2000). The internationalization of economic activities and consumer preferences cause high-tech firms to become more strategic in pooling both internal and external R&D resources together through offshore outsourcing (Bertrand and Mol, 2013) or local collaborative networks (Bresciani and Ferraris, 2014); with the objective of producing multi-technological goods which attract huge export demand from international markets (Narula, 2004).

IBM Corporation is considered as one of the foremost organisation responsible for catapulting the study of nanotechnology to the forefront of physical science research due to the fact that its multinational Research Center in Europe developed the innovative scanning probe techniques (STM and AFM) which became prevalent in the field of instrumental analysis because of the volume of nano-meter-scale information these new scanning methods provide and this earned the scientists in 1986, the Nobel Laureate Awards in Physics. R&D collaborations are critical to the technological development of high-tech firms (Laage-Hellman et al., 2017). Obtaining new competencies, conserving resources and extending complementary assets are the strategic and organisational benefits that inter-firm collaborations create (Hsu, 2006). Previous studies view successful inter-firm R&D collaborative partnerships as voluntary arrangements between organizations, which enhance the development of new innovative products and/or services through the exchange of technology and sharing of expertise (Rosenfeld, 1996; Hagedoorn, 2002; Faems, Looy and

Debackere, 2005; Roijakkers and Hagedoorn, 2006; Schleimer and Faems, 2016). Inter-firm relationships can create corporate social capital such as organizational prestige, brand recognition, and reputational status, because inter-firm networks generate intangible assets that can be accumulated through human resources (Beaudry and Allaoui, 2012).

However, collaborative partnerships divert organizational resources away from internal R&D investments (Park and Kang, 2013). Attention should be paid to the performance of collaborative partnerships in R&D projects, due to the limited internal resources of the organisations and the complexities in their external environment when participating in joint commercial arrangements. Inter-firm R&D collaboration structures can be measured by assessing the time periods in which the cooperative agreements are fulfilled between joint partners. This ranges from short-term contracts to medium-term mergers to long-term acquisitions. The governance mechanisms for robust collaborative partnerships in inter-firm R&D projects require a decentralized command system, which oversees a large amount of funds and organizes a vast amount of human capital in a specialized framework that stimulates useful, innovative engagements among all players (Scandura, 2016; Contractor and Lorange, 2002; Kumar and Dissel, 1996).

The increasingly complex, extremely expensive and highly interdisciplinary features of modern scientific activities have resulted in the rise of inter-organisational R&D collaboration (Teece, 1986); as a cost effective means for high-tech firms to access and exchange new knowledge, secure additional human capital, develop innovative methods, improve value network and enter into heavily regulated markets (Matt, Robin and Wolff, 2012); in order to benefit from the diversification of risks, transfer of scientific knowledge, enhanced market competitiveness, greater return on investment, better rate of survival, improved reputational status and brand recognition.

The antecedents to the successful commercialization of European nanotech R&D projects has been barely been covered in the literature (Von Raesfeld et al., 2012); hence, why I investigated the main internal factors which affects the innovative performance of nanotech firms across Europe; as they actively participate in a voluntary cooperative arrangement that is likely to facilitate the development of new innovative products and/or services through the exchange of technology and sharing of expertise with university partners (Huang and Chen, 2016).

In the early 2000s, nanotechnology rapidly took a strategically important role among most governments in advanced countries as a result of the recognition of its tremendous economic potential. Certain key R&D policies were initiated to quickly facilitate the commercialisation of nano-products and the convergence of nanotechnology with other technologies. Emerging economies like China and Russia have enthusiastically jumped into the bandwagon which has spurred the globalisation of nanotechnology advancement. Some management research have looked into the classification of the historical developments and future trends based on scientific publications and patent applications usually employing textual mining techniques to observe useful information from global open sources such as SCI/SSCI databases (Kostoff, et al. 2006, 2007).

There is the absence of a thorough empirical investigation which analyses the performance of nanotechnology firms and forecast the future trends for profitability of nano-products. In my study, I evaluated the key factors that influence the innovative and financial performance of nanotechnology firms from an investor's perspective and I discuss the effects of national nanotechnology initiatives on the scientific productivity and innovative, especially at the turn of the 21st century, when various government initiatives was undertaken to expedite the commercialisation of molecular engineering. The comprehensive investigation of the antecedents for a successful R&D strategy in the commercialisation of nanotechnology firms has been documented (Fiedler and Welpe, 2010); however, in this research report I would endeavour to categorise the internal and external determinants of the performance of nanotechnology firms.

1.2 Aims and Objectives

From the early decades of the 20th century, nanotechnology research studies have focused on the development and application of techniques to examine physical phenomena (Kostoff et al., 2006; 2007). Nanotechnology can be described as a multipurpose application of science that has radical innovations in processes, disruptive impact on existing industries and transformative effect in societies (Shea, 2005).

Nanotechnology will bring significant changes as profound as the industrial revolution, antibiotics, and nuclear weapons combined (Miyazaki and Islam, 2007). So, it is no surprise that governments around the world are aggressively funding nanoscience and nanotechnology in order to gain the upper hand in this very important field which would redefine many processes and systems in the near future (Shea et al., 2011). There are several motivations for nanotechnology research collaborations such as the rising costs of conducting experimental science; the availability of quick and avoidable transportation & communication facilities; the proliferation of scientific communities around the globe; the politicizing of research activities; and the strong demand for specialisation within the fields of science (Stichweh, 1996; Schott, 1991).

Nanotechnology is an example of discontinuous innovation. It is a highly intensive research and technological development science-based cluster; with complex interdisciplinary features (Schummer, 2004; Rijnsoever and Hessels, 2011). Nanotech enables multiple interactions between scientists from diverse cultural backgrounds (Katz, 1994; Kostoff et al., 2006) working for multi-faceted organizations (Heinze, 2004; Cunningham and Werker, 2012) across public and private sectors (Miyazaki and Islam, 2007) and through internationally regulated borders (Romig Jr. et al., 2007). Academic and industrial actors, as well as governments at all levels (i.e., local, regional, national and international), have allocated a considerable amount of resources to exploring the organizational structure (Fiedler and Welpe, 2010) and the technological (Corbett et al., 2000), socio-economic (Teece, 1986; Cunningham and Werker, 2012), and regulatory (Kica and Bowman, 2012) framework of nanotechnology. They aim to redefine many processes and systems in the near future (Shea, Grinde and Elmslie, 2011). Nanotech R&D collaborations embrace a multipurpose application of science that has radical innovations in processes, disruptive impact on existing industries and transformative effect in societies.

The research objective for this paper is to examine the main financial and non-financial determinants of the exit performance of VC backed nanotech portfolio companies in the United Kingdom. I want to evaluate the key performance indicators that influence the exit routes of VC backed nanotech companies. I aim to study the relationships that exist between predictors of financial performance and exit outcomes of VC investments in the UK.

In this research study, I concentrated on the key performance indicators of inter-firm R&D collaborations in nanotech industries across Europe; as nanotechnology is a highly intensive R&D science-based cluster (Mangematin and Errabi, 2012) with complex interdisciplinary characteristics (Schummer, 2004; Rijnsoever and Hessels, 2011) which promote multiple knowledge exchanges between scientists from different socio-economic backgrounds (Katz, 1994; Kostoff et al., 2006) employed in multi-faceted research organizations (Heinze, 2004; Cunningham and Werker, 2012) in both public and private sectors (Miyazaki and Islam, 2007) and across internationally regulated markets (Romig Jr. et al., 2007).

1.3 Motivations and Contributions

The motivation of my study was to investigate the main external influencers of effective collaboration in nanotech R&D projects across Europe. The key contribution of this research study is to provide policymakers and corporate strategists with useful insights into how to simplify the complexities of the environment in which nanotech firms operate. My study focuses on examining the major factors that influence the partnership size, governance mechanism, strength and duration of inter-firm relationships among nanotechnology institutions in Europe. I looked intensely at the country's legal origins, cultural dimensions, rates of economic growth, export demand for technologically advanced products, and geographical and functional proximities to industrial and funding partners of nanotech firms; while controlling for their organizational size, VC participation, and innovative capacity. The key question asked in my study is: how do the external factors affect the dynamics of collaboration in nanotech R&D projects across Europe?

The motivation of this study was dependent on my inquisitiveness in understanding the extent to which factors under management control influences the different types of innovative performance in nanotech R&D firms across the globe so as to provide corporate strategists with valuable information on the internal intricacies which expedite creativity, productivity and profitability in nanotech firms.

My study evaluates the main internal determinants of the amount of patents, quality of new product development and level of profitability of nanotech R&D organisations across the globe. I looked intensely at the human capital, financial resources and inventive assets of nanotech firms; while controlling for their previous cooperative experience, duration of collaboration and VC participation. One of the motivation of this study was dependent on my inquisitiveness in understanding the extent to which factors under management control influences the different types of innovative performance in nanotech R&D projects across Europe so as to provide corporate strategists with valuable information on the internal intricacies which expedite creativity, productivity and profitability in nanotech firms involved in R&D collaborations. My study focuses on evaluating the main internal determinants of the amount of patents, quality of new product development and level of profitability in collaborative partnerships of nanotech R&D projects across Europe. I looked intensely at the human capital, financial resources and inventive assets of nanotech firms; while controlling for their previous cooperative experience, duration of collaboration and VC participation.

Another key contribution of my study is the evaluation of the impact of financial status, value network, organisational structure, absorptive capacity and partnership size on the innovative performance of nanotech R&D projects engaged in collaborative partnerships in Europe. I then conclude by ascertaining the core internal dynamics which corporate strategists and R&D project managers need to be aware of, so as to enhance a productive inter-firm collaboration that increases the competitive advantage of high-tech firm in the EU. One of the key contributions of this research study is to provide policymakers and corporate strategists with useful insights into the internal and external environment of nanotech firms. The major factors that influence the performance of nanotechnology institutions across the globe are the country's legal origins, cultural dimensions, rates of economic growth, export demand for technologically advanced products of high-tech firms controlling for their organizational size, VC participation, and research intensity. I employed multiple regression and panel data analysis to evaluate the relationship between successful nanotech R&D firms and key performance indicator variables. I then conclude by ascertaining the core internal dynamics which corporate strategists and R&D project managers need to be aware of, as the onus is on top managers of high-tech organisations is to design simpler and flexible governance mechanisms which builds the firm's capacity to retain and integrate new knowledge and innovative techniques into existing corporate systems during periods of high financial positioning with the intention of maximizing technological productivity and commercial performance.

Traditional financial institutions such as banks are unable or unwilling to finance and monitor high-tech entrepreneurial activities due to their complexities, riskiness, illiquidity and untested markets and/or products. Over the years, VC has played an instrumental role in financing companies with little or no economic track record in order to capitalise on revolutionary discoveries in emerging and disruptive technologies like information & communication technologies (ICT) and bio-nanotechnology. During the Dot-Com economic boom in the Mid 1990s, for instance, VC firms around the world provided seed finance and other kinds of support like accounting, marketing, legal, and industry network to lots of young IT companies so as to capitalise on the huge gains from the sale of these IT stocks through various exit platforms. Thiengtham (2010) describes 'venture capital as a long term investment in equity capital of new, potentially high growth, and non-publicly traded companies that produce new and innovative products and services for new customers in new markets in return for capital gains rather than interest income and dividend yields'.

Although, VC activities have considerably and rapidly spread across the globe; Schwienbacher (2005) argues that there still exist substantial differences between the U.S. VC industry and the rest of the world particularly in areas such as - the use of convertible securities, the need for change of management upon investment and the degree of deal syndication. Nevertheless, since the advent of globalisation in the 1990s, the access OECD countries have to efficient capital markets; skilled workforce, effective intellectual property protection and sophisticated research facilities have significantly increased their VC activities (Djankov et al, 2008). According to Aizenman and Kendall (2008), the UK is regarded as one of the top net recipients of foreign VC investments because the government has endeavoured to create conducive environment that enhances VC performance. Samila and Sorenson (2009) obverse that due to the positive effects VC has on a country's sustainable economic growth and youth employment; governments around the world are eager to create a more favourable atmosphere for VC investments in order to meet stakeholders' expectations.

The demand for VC funds among young entrepreneurs is quite astonishing - about 10% of the total numbers of business plans submitted to VC firms are thoroughly screened and only 1% of the entrepreneurial concepts secure financing from GPs. The factors that significantly affect the demand for VC funds are – quality of the prospective management team, viability and profitability of the business plan/concept, prevailing market conditions, level of youth unemployment, cultural perceptions associated with business success or failure, minimum capital amount required; and the tax regimes at the head office region of the start-ups. The supply of VC funds by LPs is largely due to the - track record of the VC directors, diversification benefits accrued to the VC fund supplier, regulatory burden, cost of VC capital, religious affinity, demography, liquidity considerations, legal structure, capital gains tax regime, fund size, level of private property protection, judicial independence and cultural obligation. This report would be focusing only on the supply-side of VC investments and exits. Government agencies around the world have participated in facilitating the demand for and supply of VC funds. Policy makers in various countries have adopted schemes and instituted vehicles that enhance VC activities in order to - reduce political risk, suppress youth unemployment figures, stimulate economic growth, encourage innovation and foster wealth creation amongst its citizenry.

According to Ewing (2004), VC plays a vital role in building a vibrant private sector in EMEs through the channelling of funds to young entrepreneurs unable to access seed capital from banks due to their very low appetite to finance unproven business ventures and industries. VC investments are highly essential to EMEs due to: knowledge transfer through partnerships; high liquidity which facilitate sustained economic growth; employment generation and youth empowerment; and the identification and funding of winning firms and ideas. VC in the United States and

Europe plays the most dominant role in global VC activities due to their superior governance and free market principles. China, on the other hand, has begun to embrace more liberal economic policies in recent years and it is no surprise their VC industry has significantly grown ever since. The VC in developed countries is primarily focused on funding Bio-tech and IT/Software firms while VC in emerging markets concentrate on finance for the manufacturing and agricultural industry.

1.4 Research Questions

What are the major complexities in inter-firm R&D collaborative partnerships in a high-tech industry across Europe?

- Which external determinant influences the dimension (partnership size, governance mechanism, strength and duration) of inter-firm R&D collaborative partnerships in nanotech organisations across Europe?
  - Can the geographical and functional proximity to partners influence the dimension of collaboration in nanotech R&D projects?
  - Do cultural dynamics have an impact on the dimension of collaboration in nanotech R&D projects?
  - Is the legal origin of a country about to influence the dimensions of collaboration in nanotech R&D projects?
  - Does a country's rate of economic growth affect the dimensions of collaboration in nanotech R&D projects?

- Which key internal factor influences the innovation and financial performance (patents, new product development and long-term profitability) of nanotech R&D organisations?
  - How does the level of value network of nanotech R&D organisations affect the innovation and financial performance?
  - Does the absorptive capacity of nanotech R&D organisations influence their innovation and financial performance?
  - Can VC fund manager's participation in nanotech R&D organisations influence their innovation and financial performance?

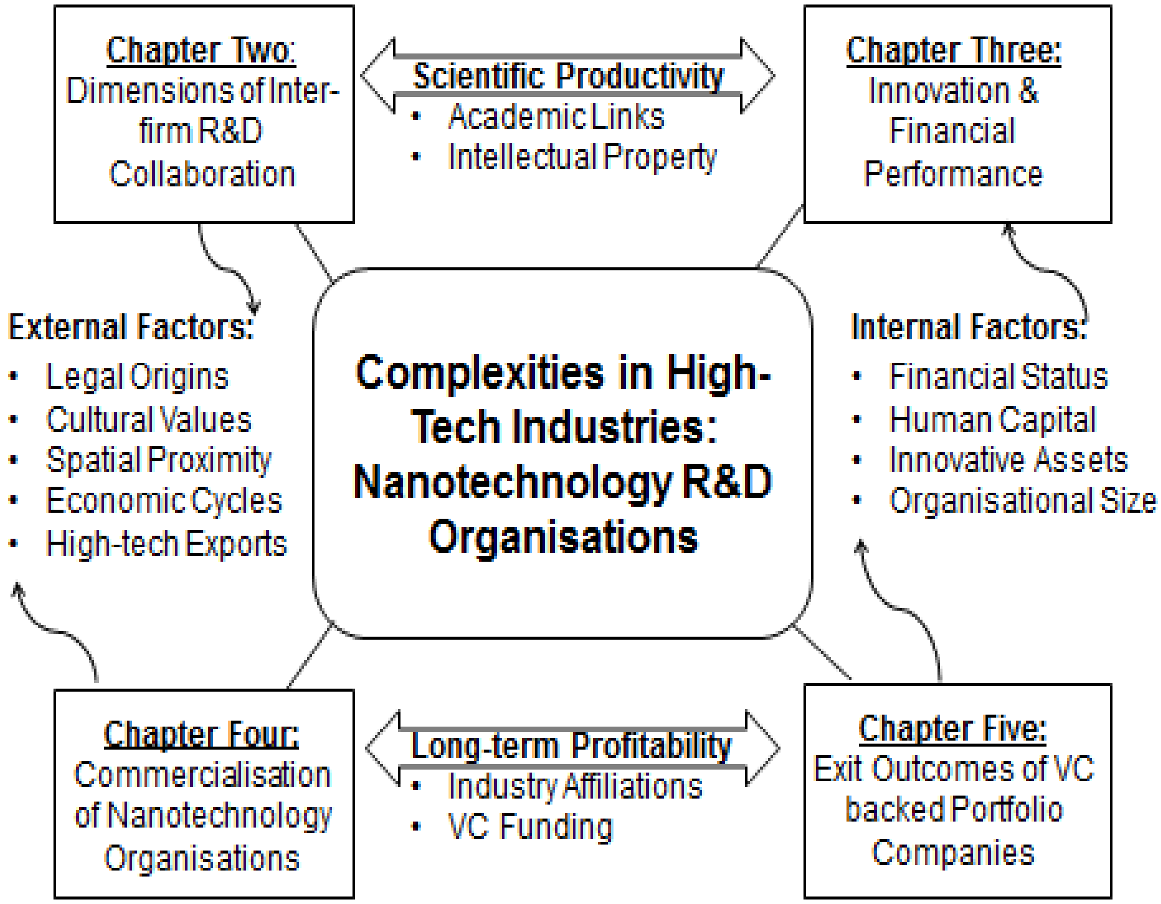
What are the main factors that determine a country's innovation and financial firm performances in nanotechnology industries during commercialization?

- How has nanotech R&D organisations across the globe performed in the period of commercialisation?
- What were the historical developments in basic and applied research and the modern periods of nanotechnology commercialisation?

What factors influence the exit performance of VC and non-VC backed nanotech portfolio companies?

- What are the financial and non-financial factors that significantly influence the exit performance of VC backed nanotech portfolio companies?
- Do VC financing affect the exit performance of nanotech portfolio companies?
- Do foreign funded nanotech portfolio companies have better exit performance than their domestic funded counterparts?

Figure 1.1: Diagram of Research Questions linking other Sections



1.5 Thesis Structure

The study is structured as follows: In chapter 2, I would introduce the theoretical framework of the study on the external complexities and develop the hypothesis. Section 2.3 outlines the research methodology. The empirical results are presented in section 2.4. The section 2.5 discusses these results and highlights research and policy implications. Section 2.6 concludes with the pa's contributions and its limitations and suggests for further research. Chapter 3 would focus on the internal intricacies affecting R&D collaborations. Chapter 4 and 5 focus on the organisational performance in terms of innovation, finance and exit behaviour. I introduce the theoretical framework of the study and develop the hypothesis. Section 4.3 and 5.3 outlines the research methodology. The empirical results are presented in section 4.4 and 5.4 show the results and highlights research and policy implications. Finally, Chapter six summarizes and concludes with future recommendations.

Chapter 2: External Complexities in Nanotechnology R&D Projects: Analysis of Inter-firm Collaborative Partnerships that Lead to Abundance

2.1 Introduction

From the early decades of the 20th century, nanotechnology research studies have focused on the development and application of techniques to examine physical phenomena (Kostoff et al., 2006; 2007). Nanotechnology can be described as a multipurpose application of science that has radical innovations in processes, disruptive impact on existing industries and transformative effect in societies (Shea, 2005). Collaboration is usually peculiar among experimental research due to its interdisciplinary features and the use of large or complex instrumentation such as telescopes and CT scanners (Lee, 1996; Bozeman and Corley, 2004). One of the main reasons for the surge in scientific research collaborations is due to the growth in interdisciplinary research institutes such as nanotechnology departments, which rely on the combination of the expertise of researchers from different fields of study (Schummer, 2004).

Research collaboration in nanotechnology could be observed as the meaningful cooperation of researchers in achieving a collective goal of creating and disseminating new scientific knowledge on an atomic scale. Collaboration in scientific exploration can be developed among individual researchers such as interdisciplinary groups; across public/private sectors such as university and industry; and between countries such as multi-national cooperative institutes (Fiaz, 2013; Ponomariov, 2013). There are several motivations for nanotechnology research collaborations such as the rising costs of conducting experimental science; the availability of quick and avoidable transportation & communication facilities; the proliferation of scientific communities around the globe; the politicizing of research activities; and the strong demand for specialisation within the fields of science (Stichweh, 1996; Schott, 1991).

The results of systematically assessing international research collaborations in nanotechnology elucidate the associations between national research policies and the development of transnational scientific networks (Romig et al., 2007). Governments around the globe have provided resources as well as incentives to promote rapid growth and dissemination of scientific knowledge as a means of facilitating international collaborations; in order to promote indigenous innovation, exploit research synergy, and enhance scientific excellence (Tang and Shapira, 2012). The pathway to a contemporary global scientific community usually goes through a transitionary period of strong nationalistic identity in science and technology (Heinze, 2004; Mehta et al., 2012). In order words, the nationalization of reference groups is compensated in due course by the addition of new processes and systems into an existing scientific community by means of a progressive internal differentiation of science and technology. Nanotechnology will bring significant changes as profound as the industrial revolution, antibiotics, and nuclear weapons combined (Miyazaki and Islam, 2007). So, it is no surprise that governments around the world are aggressively funding nanoscience and nanotechnology in order to gain the upper hand in this very important field which would redefine many processes and systems in the near future (Shea et al., 2011).

The European Commission actively invests into joint R&D projects[1], in conjunction with the private sector, to facilitate inter-firm collaboration and scientific performance in an attempt to foster global competitiveness (Paier and Scherngell, 2011). A key challenge for European R&D policy makers is to define an optimal collaboration scale for fund mobilization across local, regional, national and international cooperative partnerships to promote a vibrant and prosperous socio-economic environment Previous studies view successful inter-firm R&D collaborative partnerships as voluntary arrangements between organizations, which enhance the development of new innovative products and/or services through the exchange of technology and sharing of expertise (Rosenfeld, 1996; Hagedoorn, 2002; Faems, Looy and Debackere, 2005; Roijakkers and Hagedoorn, 2006; Schleimer and Faems, 2016).

Inter-firm R&D collaboration structures can be measured by assessing the time periods in which the cooperative agreements are fulfilled between joint partners. This ranges from short-term contracts to medium-term mergers to long-term acquisitions. The governance mechanisms for robust collaborative partnerships in inter-firm R&D projects require a decentralized command system, which oversees a large amount of funds and organizes a vast amount of human capital in a specialized framework that stimulates useful, innovative engagements among all players (Scandura, 2016;

[1] Through its 7th framework programme for research funding which lasted from 2007 to 2013, the EU disbursed €28 billion and its current Horizon 2020 is estimated at €80 billion (EU report card, 2017).

Contractor and Lorange, 2002; Kumar and Dissel, 1996). Collaborative partnerships divert organizational resources away from internal R&D investments (Park and Kang, 2013). Therefore, it is important that attention is paid to the size of collaborative partnerships in R&D projects, due to the limited internal resources of the organisations and the complexities in their external environment when participating in joint commercial arrangements.

Nanotechnology is an example of discontinuous innovation. It is a highly intensive research and technological development science-based cluster; with complex interdisciplinary features (Schummer, 2004; Rijnsoever and Hessels, 2011). Nanotech enables multiple interactions between scientists from diverse cultural backgrounds (Katz, 1994; Kostoff *et al*., 2006) working for multi-faceted organizations (Heinze, 2004; Cunningham and Werker, 2012) across public and private sectors (Miyazaki and Islam, 2007) and through internationally regulated borders (Romig Jr. *et al*., 2007). Academic and industrial actors, as well as governments at all levels (i.e., local, regional, national and international), have allocated a considerable amount of resources to exploring the organizational structure (Fiedler and Welpe, 2010) and the technological (Corbett *et al*., 2000), socio-economic (Teece, 1986; Cunningham and Werker, 2012), and regulatory (Kica and Bowman, 2012) framework of nanotechnology. They aim to redefine many processes and systems in the near future (Shea, et al., 2011).

Most policy initiatives and organizational strategies are geared towards facilitating collaboration, not only on the level of individual scientists (Wagner and Leydesdorff, 2005), but also on a higher level of inter-firm cooperative engagements (Wong, Ho, and Chan, 2007). The merits of inter-firm collaborations in nanotechnology industries are the diversification of risks in an uncertain environment and the transfer of knowledge among cooperative partners (Park and Kang, 2013). It has been found that organizations that are highly involved in collaborative partnerships enhance their competitiveness, experience greater return on their investment and enjoy a much higher rate of success (Todeva and Knoke, 2005). Inter-firm relationships can create corporate social capital such as organizational prestige, brand recognition, and reputational status, because inter-firm networks generate intangible assets that can be accumulated through human resources (Beaudry and Allaoui, 2012).

The motivation of my study was to investigate the main external influencers of effective collaboration in nanotech R&D projects across Europe. The key contribution of this research study is to provide policymakers and corporate strategists with useful insights into how to simplify the complexities of the environment in which nanotech firms operate. My study focuses on examining the major factors that influence the partnership size, governance mechanism, strength and duration of inter-firm relationships among nanotechnology institutions in Europe. I looked intensely at the country's legal origins, cultural dimensions, rates of economic growth, export demand for technologically advanced products, and geographical and functional proximities to industrial and funding partners of nanotech firms; while controlling for their organizational size, VC participation, and innovative capacity. The key question asked in my study is: how do the external factors affect the dynamics of collaboration in nanotech R&D projects across Europe?

In this study, both quantitative and qualitative research methods were used to generate secondary and primary data to enrich the sample and provide adequate observational data for the analysis. I collected secondary data on nanotechnology organizations and their industry affiliations, organizational size (total assets), number of patents, and VC participation from the Orbis database provided by Bureau van Dijk (BvD). As I was unable to find useful proxies for collaborative dynamics of nanotechnology organization in the secondary dataset, I then used a survey instrument to generate vital interview and questionnaire data. The responses were coded into ordinal observations on the dimensions of collaboration and the geographical and functional proximities to industrial and funding partners. I conducted 30 interviews with top executives of nanotech firms and provided 97 questionnaires to senior administrators of nanotech R&D projects across 12 European countries. Finally, I included the legal origin index developed by La Porta et al., (1999) for all the nanotech R&D projects in the dataset, and carried out ordinary least square (OLS) and logistic regressions to provide empirical tests for my hypotheses.

The results show that external factors – such as the geographical and functional proximities to key partners, a country's legal origin, cultural dimensions, economic growth and its export demand for advanced high-tech products – meaningfully influence the size and governance mechanism, strength and duration of collaboration in nanotech R&D projects. The closeness, regarding geography and functional space, of nanotech R&D firms most influences the dimensions of their R&D collaborations. Also, nanotech firms operating in countries with French Civil Law origin are inclined to establish a centralized system of governance in their R&D collaborative partnerships, due to the high level of legal predictability. Countries with a legal origin in English Common Law are less predictable, while those with French Civil Law are less flexible (Beck *et al*., 2003). I also find that VC funding in nanotech R&D projects usually leads to VC's active participation in the strategic management of these collaborative partnerships, in particular to influence the size and duration of the cooperative engagements.

Moreover, my results show that the innovative capacity and organizational size of nanotech firms also affect the dimensions of their R&D collaborations (Fiedler and Welpe, 2010). I argue that, because nanotech R&D projects are inherently very complex, nanotech firms that operate with a more decentralized internal organizational structure and in a simpler external environmental framework will be more effective in their R&D collaborations and hence can produce better innovative outcomes for a more abundant world. My study concludes by identifying the possible opportunities and challenges for policy makers and organizational strategists to exploit or guard against, to enhance the dimensions of collaboration within the nanotechnology industry or similar emerging and discontinuous innovations.

The study is structured as follows: In section 2.2 I introduce the theoretical framework of the study and develop the hypothesis. Section 2.3 outlines the research methodology. The empirical results are presented in section 2.4. The section 2.5 discusses these results and highlights research and policy implications. Section 2.6 concludes with the pa's contributions and its limitations and suggests for further research.

2.2 Theoretical Framework

Scientific activities are organised by individuals who operate under local, regional, national and international institutions at various levels of spatial proximity and who are in communication with one another in order to create and diffuse scientific knowledge (Ponds et al., 2007). Collaboration among scientists from different societies implicitly confirms and explicitly reinforces their belief in the virtues of universal validity as it fosters consensus and facilitates diffusion within the scientific community (Katz and Martin, 1997). The prerequisite for a global diffusion of scientific knowledge is prevalent in the belief in universal validity, wider dissemination, and intensive collaboration (Lee and Bozeman, 2005). One of the salient determinants of the global interconnectedness of scientific communities is the complex dynamics of the internal differentiation of science (Corbett et al., 2000).

The international interconnectedness of scientific communities is not due to the emergence of a unipolar world of scientists who have similar objectives or share a common set of normative and cognitive presumptions; but akin to continuous proliferation of ever new societies of scientists with increasingly constrained jurisdictions that standardizes the social and cognitive universe of science in a way which is irreconcilable with the confines of national scientific societies (Kica and Bowman, 2012). The factors contributing to collaboration within scientific communities as: changes in levels of funding; desire for visibility and recognition among researchers; increasing demand for the rationalisation of scientific manpower; rapid specialisation in science; and growing proliferation of science (Zheng et al., 2014). The custom among scientific research communities for some years now has been collaboration and this is due to the increasingly complex, very expensive and highly interdisciplinary characteristics of modern scientific endeavours (Teece, 1986).

Collaboration on an international scale is a network of self-organising researchers with preferential attachments and social constraints (Wagner and Leydesdorff, 2005). Most policy initiatives are geared at facilitating collaboration not on individual basis but on a higher level of public/private or foreign partnership (Fiedler and Welpe, 2010). National scientific institutions usually function as a policy initiative due to the reliance on state funds. In contrast to the European scientific community, emerging economies (such as the Chinese) scientific development was led by state actors and tailored towards the applied sciences (Macnaghten et al., 2005). The international collaborative networks are very dynamic, rapidly increasing, and highly influential. Collaboration in scientific communities provides several benefits such as the transfer of knowledge, skills and techniques; the cross-fertilisation of concepts and ideas; the provision of intellectual companionship; and enhancing of the prominence of research work.

Multi-author papers can be used as a proxy for measuring the level of collaboration among research groups (Smith, 1958). Although, co-authorships in scientific publications simply provide partial insight into the level of collaboration between two or more researchers due to the fact that; the accurate nature and size of collaboration cannot be clearly determined by survey techniques. Collaboration is a robust predictor of publishing productivity when the total number of scientific publication is used as its measurement but when the allocated contribution is weighted into the number of authors, collaboration does not significantly relate to publishing productivity as other factors are kept constant (Jong and Slavova, 2014).

Scientific research is profoundly different from industrial innovation because the former is primarily concerned with adding and diffusing new knowledge into the existing body of knowledge while the latter is more interested in adding to the streams of income from the exclusive rights of hoarding private information (Bozeman and Gaughan, 2007). Intellectual property rights provide an acquisition platform for small and medium enterprises. The global exploitation of science and technology by multi-national corporations better describes the much greater rate of growth of international patent applications than the growth rate of national patent applications (Alcacer and Gittelman, 2006).

According to the findings of Pond et al., (2007), when geographical proximity is high amongst science based technologies between universities, companies and government research institutes; collaboration in scientific research is apparently more likely to be successful since their physical distance is close because of the tacit character of knowledge which requires face-to-face interaction. High geographical proximity can compensate for the deficiencies in institutional differences during collaboration; that is, research collaboration concerning different types of organisations is more spatially localised because of shared interest in labour exchange, access to local funding, and mutual trust facilitated by informal contact and interactions. The closer potential collaborators are in geographical proximity; the more likely there could be an informal communication among them which leads to a collaborative event (Dietz and Bozeman, 2005).

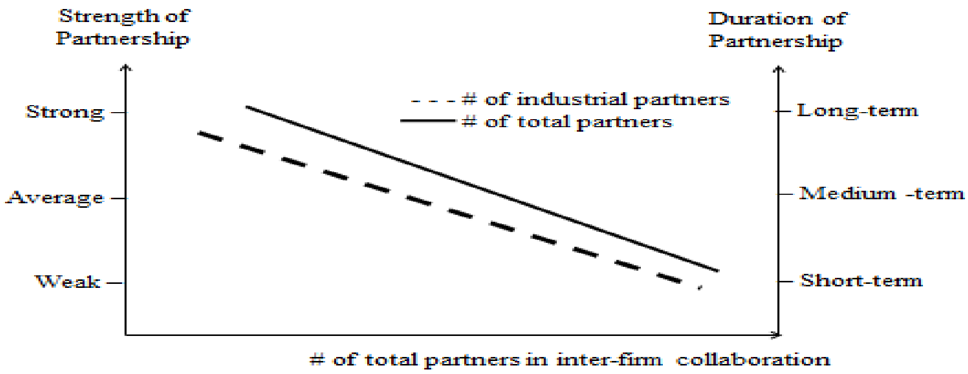
In terms of the legal factors that influence the level of collaboration within nanotechnology organisations, historically determined differences in the legal traditions of countries could help explain the discrepancies in the collaborative size and efficiency of institutions within the global scientific community (Beck et al., 2003). I adopt the theory of law and finance initiated by La Porta et al., (1999) which proves that countries with English Common law origins generally possess stronger shareholder and creditor protection than countries with French, German or Scandinavian legal origins (La Porta et al., 2008). Countries that adopt the Common law better protect investors against expropriations due to the effectiveness of its legal enforcement which signifies the independence of the judiciary which reduces agency problems and results in higher dividend pay-outs (Djankov et al., 2008). Superior alternative financial markets are usually found in English Common law countries due to the fact that shareholder's rights are better protected through the court system (Cumming, 2008). Also, stricter bankruptcy laws in a country attract greater external funding and direct investments into risky entrepreneurial ventures (Armour and Cumming, 2008).

Inter-firm relations management capabilities can be defined as the structure, processes, and tools that equip companies to seize, distribute, accumulate and use information gathered from the collaborative activities carried out with other partners (Niesten and Jolink, 2015). Inter-firm relations management capabilities are vital determinants of effective collaboration, because they allow the partners in a cooperative arrangement to easily modify the key features of their relationship to mitigate any unforeseen external threat to it. Collaborative arrangements help reduce R&D costs and mitigate business risks in new projects. Partners with a higher level of inter-firm relations management capabilities tend to influence partners with lower levels in any collaborative partnership (Contractor and Lorange, 2002).

2.2.1 Strength and duration of collaborative partnerships

Figure 1 depicts a proposed model for the relationships between the strength and duration of collaboration and the size of the cooperative partnership. I see from the model below that the greater the strength and the longer the duration of R&D collaboration, the lesser the number of their partners. As the strength and duration increases, the sizes of both industrial and overall partners will most likely decrease, based on the interaction effects between the two variables. Thus, as a policy implication I can infer that for collaborative partnerships in high-tech industries to be strong and lasting, the number of the partners must be reduced to the most optimal level.

Figure 2.1: Strength and Duration of Collaborative Partnership Models



In *figure 1* above, I illustrate that effective inter-firm collaboration is dependent not only on the number of partners but also on the quality of input delivered into the nanotech R&D projects over a sustained period of time. My proposed model is based on the data sample of this study. It was constructed from the relationships between three of my dependent variables, taking into account the partner's size, the strength of the value network and the duration for completing the R&D projects. I observe that the strength of partners decreases from strong to weak the more partners a company has, because R&D projects tend to explore multiple concepts initially and later focus on a few productive trends that guarantee fast innovative outcomes. Also, the duration of partnership decreases from long-term to short-term the more partners a company has, because as R&D projects become more successful through the patenting of new ideas or development of new products, a centralized governance mechanism emerges and reduces the need for more industrial partners.

2.2.2 Proximity as an influencer of R&D collaboration

Proximity is considered to be the closeness between two economic actors in terms of their distance, network and firm size (Boschma, 2005). Collaborations in European nanotech companies are not random and are facilitated by different kinds of proximities such as organizational, technological, geographical, functional, cognitive, sectoral and social proximity (Cunningham and Werker, 2012). Social network and spatial or geographical proximity have an important influence on the level of R&D collaboration among nanotech companies (Autant-Bernard *et al.,* 2007). On the other hand, the physical closeness between collaborators is more important when there are institutional differences (Ponds *et al.,* 2007). However, due to advances in information and communication technologies, the physical distance between companies does not singularly affect their ability to collaborate in R&D projects (Torre, 2008). Nevertheless, informal and face-to-face interaction among scientists is critical in facilitating research collaborations (Katz, 1994; Balland, 2012). The time and cost it takes to interact are more important than the pure distance between collaborators (Lundquist and Trippl, 2013). The functional linkages or proximity among cooperative partners facilitates their performance (Koch and Strotmann, 2006).

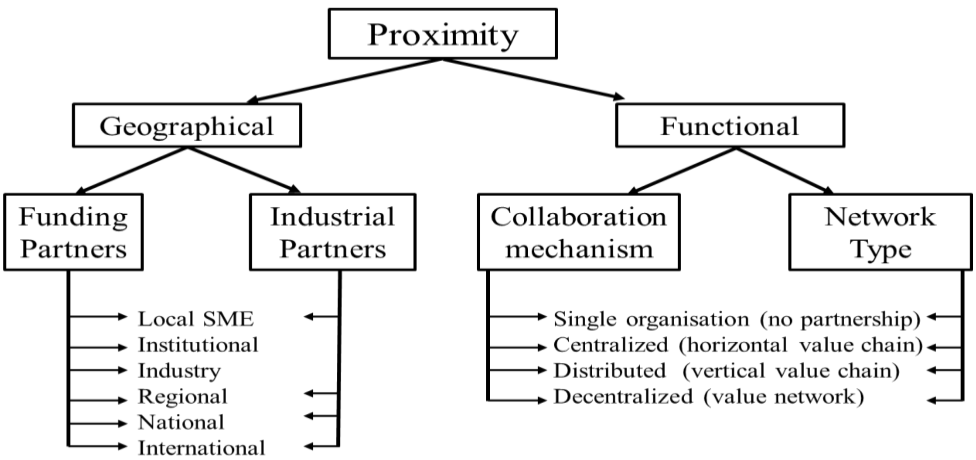
One of the main reasons for the surge in scientific research collaborations is due to the growth in interdisciplinary research institutes, which rely on the combination of the expertise of researchers from different fields of study. Scientific activities are organized by individuals or organizations that operate under local, regional, national and international institutions at various levels of spatial proximity, and who are in communication with one another to create and diffuse scientific knowledge. When geographical proximity is high, collaboration in scientific research development is apparently more likely to be successful, since a shorter physical distance is required in face-to-face interaction as a result of the tacit character of knowledge. High geographical proximity can compensate for the deficiencies in institutional differences during collaboration; that is, research collaboration concerning different types of organizations is more spatially localized because of shared interest in labor exchange, access to local funding, and mutual trust facilitated by informal contact and interactions. The closer potential collaborators are in geographical proximity, the more likely is informal communication among them, which could lead to a collaborative project.

Functional proximity is regarded as the operational nearness in terms of the ease and timing of one-on-one conversations (Monge and Kirtse, 1980). It reflects the capability of partners within a collaborative arrangement to organize face-to-face meetings in a matter of one working day (Moodysson and Jonsson, 2007). Functional proximity facilitates inter-firm relationships, by identifying easier communication and networking platforms that promote the emergence of a group or region-specific values (Belin and Monteil, 1999). Taking into account the quality of interactive channels and the shared areas within a geographical region provides partners with an opportunity to explore useable distances or passive contacts. Functional proximity changes over time, while geographical proximity is considered to be fixed. In Figure 2, I propose a proximity model where nanotech companies could be affected by two major forms of proximity: geographical and functional.

H1a: The higher the geographical proximity to key partners; the greater the number of partners, the more centralized the governance mechanism, the stronger the value network and the longer the duration of collaborative partnerships in nanotech R&D Projects.

H1b: The higher the functional proximity to key partners; the greater the partner's size, the more centralized the governance mechanism, the stronger the value network and the shorter the duration of collaborative partnerships in nanotech R&D Projects.

Figure 2.2: A proposed model for proximity influence on collaboration



2.2.3 Effects of legal origin on R&D collaboration

In the literature, the modern inter-firm networks are highlighted as hybrid arrangements, which are typically comprised of suppliers, customers, competitors, regulatory bodies, and financial institutions (Todeva and Knoke, 2005; Contractor and Lorange, 2002). The advent of globalization and the homogeneity of regulations in countries have created more opportunities for companies to collaborate internationally and increase their competitive advantage (Van Beers and Zand, 2014). As a way of facilitating collaborations around the globe, governments have provided resources and incentives to promote the rapid growth and dissemination of scientific knowledge, in order to encourage indigenous innovation, exploit research synergy, and enhance scientific excellence. The pathway to a contemporary global scientific community usually goes through a transitionary period of strong nationalistic identity in science and technology.

The main external threats to effective international collaboration in R&D projects are foreign language predicaments, dissimilar legal systems, regulatory barriers, and domestic cultural difficulties (Bjorkman *et al.*, 2007). Regarding the legal dynamics that impact the level of collaboration in nanotech organizations, historically determined variances in the legal traditions of countries could help explain the differences in the collaborative size and efficiency of institutions within the global scientific community (Beck *et al.*, 2003). I adopted the theory of law and finance initiated by La Porta *et al.,* (1999), which stipulates that countries with English Common Law origin generally possess stronger shareholder and creditor protection than countries with French, German or Scandinavian Law origins (La Porta *et al.*, 2008).

In order words, countries that adopt the English Common Law better protect investors against expropriations due to the effectiveness of its legal enforcement, which highlights the independence of the judiciary and reduces agency problems that result in higher dividend pay-outs (Djankov *et al.*, 2008). Superior alternative financial markets are found in countries with English Common Law origin, because shareholders' rights are better protected through the court system (Cumming, 2008). Building on this literature, I propose that a country's legal origin significantly influences the number of partners, the governance mechanism, strength and duration of R&D collaborations.

H2a: If inter-firm R&D projects are carried out within the jurisdiction of countries with French Civil Law origins; the number of partners reduces, the governance mechanism is centralized, the duration decreases and there is a weak value network in the collaborative partnerships of nanotech firms when compared with English Common Law Countries.

H2b: If inter-firm R&D projects are carried out within the jurisdiction of countries with German Civil Law origins; the number of partners reduces, the governance mechanism is centralized, duration decreases and there is a weak value network in *the collaborative partnerships of nanotech firms when compared with English Common Law Countries.*

H2c: If inter-firm R&D projects are carried out within the jurisdiction of countries with Scandinavian Civil Law origins; the number of partners reduces, the governance mechanism is centralized, duration decreases and there is a weak value network in the collaborative partnerships of nanotech firms when compared with English Common Law Countries.

2.2.4 Cultural dimensions in R&D collaboration

As R&D partnerships become more global, understanding national cultures becomes essential because it partly determines cooperative performance and affects the attainment of organizational goals (Franke *et al.,* 1991). Culture is an established set of values that affects the way people think and behave within society, and which is passed down from generation to generation (Bosley, 1993). Globalisation has facilitated the increase of trade among nations, and this has resulted in the convergence of cultures and collision of linguistic practices (Basu and Yoshida, 2012).

Based on a cross-country study that analyzed certain cultural effects on business organizations, it could be argued that the attitudes of professionals can be derived from their religions and another cultural phenomenon (Hofstede, 1983). As such, cultural variables explain the discrepancies in investor protection rights better than the legal traditions of countries, and key indicators such as language and religion affect financial market and technology development. Cultural differences affect the transfer proficiencies of companies in global inter-firm relationships through vital determinants such as social assimilation and prospective absorption capacity (Bjorkman *et al.,* 2007; Licht *et al.,* 2001).

The careful consideration of the cultural dynamics in inter-firm relations is a useful skill 21st-century managers need to possess to develop trust and enhance creativity in collaborative engagements (Chua, Morris, and Mor, 2012). Cross-cultural collaborations in high-tech industries experience lots of difficulties, which could be circumvented by choosing the right R&D project to be subcontracted and by estimating its possible cooperative outcome (Krishna *et al.,* 2004). There are four main cultural dimensions that act as differentiators to capture the complex nuances that describe culture (Hofstede, 1983). These cultural dimensions are: power distance, which is the extent to which the masses within a society accept that power is unevenly distributed; uncertainty avoidance, which is the degree to which tolerance for uncertainty and ambiguity is allowed or acceptable; individualism vs collectivism, which is the level to which people within a society are interdependent and are easily integrated into and committed to groups; and masculinity vs femininity, which is the degree to which a society is influenced by historically masculine or feminine values. However, I focused on the tolerance level of uncertainty and scale of female participation in science and technology fields when compared with their male counterparts. We, therefore, propose the following hypotheses:

H3a: The greater the degree of society's intolerance for ambiguous and uncertain business ventures, the lower the overall partnership size, the more centralized governance mechanism, the weaker the value network and the shorter the duration of collaborative partnerships in nanotech R&D projects.

H3b: The higher the degree to which masculine values prevail in society over feminine values, the greater the partnership's size, the more centralized the governance mechanism, the shorter the duration and the weaker the value network of collaborative partnerships in nanotech R&D projects.

2.2.5 Economic growth and R&D collaboration

Cultural values are economic performance determinants, which provide a useful explanation for the cross-national variance in economic growth of nations (Franke, Hofstede, and Bond, 1991). There is a positive relationship between the economic growth rate within a country and their level of human capital accumulation (Strulik, 2005). The rationale for R&D cooperation and the size, structure, and time-frame is solely dependent on the net gains from the collaborative partnerships (Van Beers and Zand, 2014). The motives behind organizations undertaking inter-firm collaboration vary vastly and are dependent on firm-specific features and multiple environmental factors. Motives include: to increase their capacity to produce; decrease internal weaknesses and external threats; achieve greater control and organizational flexibility; realize market potential and obtain competitive advantage, leading to enhanced profitability and rapid growth (Todeva and Knoke, 2005).

Inter-firm cooperation has grown rapidly over the last 20 years because of the dynamic nature of the external environment of R&D projects. In other words, companies that have several collaborative arrangements with diverse partners are expected to have a more synergetic outcome in product development and receive complimentary information in the organizational learning. Cooperative engagements between high tech companies are used as market entry strategies into industries tightly controlled by the government to circumvent regulatory constraints during periods of economic growth, thereby improve market conditions and strengthen their industry positions (Contractor and Lorange, 2002). In line with the literature I propose the following hypothesis:

H4: The higher the rate of economic growth within a country, the greater the partner's size, the more decentralized the governance mechanism, the stronger the value network and the longer the duration of collaborative partnerships in nanotech R&D projects.

2.2.6 International demand for technologically-advanced products

The main factors that determine the successful internationalization of commercial products are the harmonization of regulated markets and the technological sophistication of business ventures. These factors have different impacts on small- and medium-scale enterprises (SMEs) and large firms (Broocks and Van Biesebroeck, 2017). Most SMEs are required to be systematic in their product selection and strategic planning, in order to circumvent the inherent weaknesses of not having an adequate market niche and financial flexibility.

In contrast, large firms have sufficient financial resources to ensure that their focus is on non-price marketing instruments (i.e., product, promotion, and place) that could enhance international demand for their new or existing products (Cavusgil and Kirpalani, 1993). A firm's export intensity is highly dependent on the quality of their products, because economic growth is significantly influenced by total factor productivity, which arises from the innovative performance of high-tech firms (Curzi and Olper, 2012). Higher export performance is usually associated with efficient, innovative firms that can create top-quality products at reasonably high prices for effective distribution to distant markets (Fajgelbaum, Grossman and Helpman, 2011). Globalisation influences the scale and scope of multi-product firms via competition and demand effects (Eckel and Neary, 2010).

H5: The higher the export demand for a country's technologically advanced products, the greater the number of partners, the more centralized the governance mechanism, the shorter the duration and the stronger the value network of collaborative partnerships in nanotech R&D projects.

2.2.7 Organizational size and R&D collaboration

The international collaborative networks are very dynamic, rapidly increasing, and highly influential. External networking compliments the internal R&D activities of SMEs when economies of scale and/or integration of diverse skills and technologies could be achieved (Mancinelli and Mazzanti, 2009). Compared with large companies, SMEs are significantly unable to establish the most suitable external network of partners for collaboration (Rothwell and Dodgson, 1991). As SMEs have smaller external relations than large companies, they are more confined to their local region because of the need to have direct interactions in tacit knowledge exchange. Large firms are far more likely to have a cooperative relationship with the vertical partners (such as universities, research institutes, and training centers) in their supply chain than SMEs. However, technology-driven SMEs are uniquely different in this regard.

The inability of SMEs to engage in vast cooperative partnerships, outside their business relations, is due to the low financial resources available and the small number of employees capable of initiating and preserving network links (Kaufmann and Todtling, 2002). As far as external network relations are concerned, SMEs are focused more on developing regional partnerships than are large companies. Multi-national corporations (MNCs) have a competitive advantage, resulting from their superior ability to transfer and combine competencies across geographically dispersed entities. The global exploitation of science and technology by MNCs better describes the much greater rate of growth of international patent applications than the growth rate of national patent applications (Todeva and Knoke, 2005; Bjorkman *et al.,* 2007). However, it is extremely problematic for MNCs to pursue speculative opportunities and/or mitigate unestablished threats posed by disruptive innovations, due to their cultural and structural impediments (Lindsay and Hopkins, 2010).

H6: The larger the organizational size of nanotech firms, the lesser the number of partners, the more centralized the governance mechanism, the shorter the duration and the stronger the value network of R&D collaborative projects.

2.2.8 VC Fund Manager's Participation in R&D projects

Venture capital (VC) is an independent, professionally managed, dedicated pool of capital that focuses on equity or equity-related investments in privately held, high-growth companies (Gompers and Lerner, 2001). VC funds are a collective investment scheme used in making investments in various portfolio companies. A large portion of the global VC industry operations can be attributed to the entrepreneurial spirit prevalent in the United States. Also, the access OECD countries have to efficient capital markets, skilled workforces, effective intellectual property protection and sophisticated research facilities enhance their VC activities and performance (Djankov *et al.*, 2008). VC plays a vital role in building a vibrant private sector by channeling funds to young entrepreneurs, who are unable to access seed capital from banks due to their reluctance to finance unproven business ventures and industries (Ewing, 2004). VC investments are essential to SMEs due to: knowledge transfer through partnerships; high liquidity, which facilitates sustained economic growth; employment generation and youth empowerment; and the identification and funding of winning firms and ideas.

The internationalization of the VC industry in the 1990s has allowed for a vast and steady increase in cross-border VC investments around the world, such that foreign VC participation in local portfolio companies now accounts for one-third of global VC activities (Schertler and Tykvova, 2012). One of the effects of globalization has been the facilitation of cross-border VC activities, due to the relative ease of labor restrictions, capital controls and banking regulations among developed countries and emerging markets (Wang and Wang, 2011). VC fund managers participate in the strategic management of portfolio companies they have invested into, to monitor and influence the activities of the board of directors. As VC-funded companies usually reach maturity within 5-7 years, divestments become essential due to the need to ensure the liquidity of VC funds, distribute returns, evaluate performance and/or reallocate entrepreneurial finance.

H7: The participation of VC fund managers in nanotech R&D projects increases the number of partners, centralizes the governance mechanisms, shortens the duration and strengthens the value network of collaborative partnerships.

2.2.9 Innovative capacity and R&D collaboration

Collaboration in scientific communities provides several benefits, such as: the transfer of knowledge, skills, and techniques; the cross-fertilization of concepts and ideas; the provision of intellectual companionship; and increasing the prominence of research work. The use of intellectual asset strategies in preserving opportunities for, or avoiding threats from, disruptive innovations is critical to the survival of R&D organizations, because of the most likely loss in their market position (Lindsay and Hopkins, 2010). Patents and other intellectual property should be used to meet the needs of low-end and prospective customers.

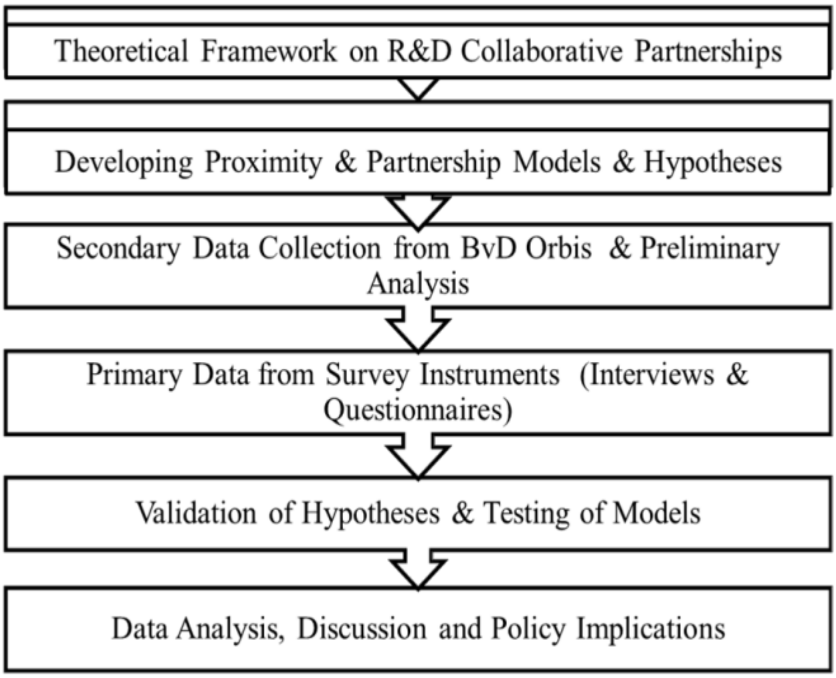
In university-industry partnerships, there are valid financial considerations for supplementing patents with publications. The fear of misappropriation and the cost of knowledge transfer impede the formation of inter-firm relationships, due to the knowledge intensity of firms and the stickiness in transferring vital information among their supply chain (Contractor and Lorange, 2002). The innovative capacity of a high-tech organization is their ability to develop and commercialize innovative ideas, products, and services over a sustained period of time (Guan and Ma, 2003). It represents R&D firm management's effectiveness in converting scientific and technical productivities into profitable, innovative marketable products, which could drive radical and/or disruptive technologies into the marketplace to dominate industries (Koc and Ceylan, 2007).

H8: The greater the innovative capacity of nanotech firms involved in R&D projects, the lower the number of partners, the more centralized the governance mechanism, the shorter the duration and the stronger the value network of their collaborative partnerships.

2.3 Research Design

In this study, I employed a mixed research method to critically examine the external complexities that affect the dimensions of collaboration in nanotech firms. Figure 3 shows the research outline of this study. The conceptual framework is based on theories of inter-firm relations, proximities in collaborative partnerships, national culture influences on inter-organizational behavior, legal origin as a determinant of financial development, and the international demand for technologically advanced products. These theories provide the basis for constructing and testing my hypotheses to produce empirical results on the external factors that affect the dimensions of inter-firm collaborations in nanotech R&D projects across Europe.

Figure 2.3: Research outline of the study



2.3.1 Data

The collaborative R&D projects in my data sample involve various characteristics of nanoscience and nanotechnologies, such as the development of nanotubes and nanowires for electrical and biological consumption, plus the use of nanoparticles and the construction of nano-instruments for manufacturing and communication purposes. These nanotech R&D projects include but are not limited to: electrical discharge machining, multi-component injection molding, electroforming, powder injection molding, nanoimprinting, X-ray lithography, selective laser sintering, chemical vapor deposition, nanometer-scale measurement and future tooling technology.

I adopted a mixed research method where both quantitative and qualitative data were used to enrich the process of data collection and analysis. I collected secondary data on the organizational size, some patents, VC participation and industry and academic links to nanotech R&D projects from the Orbis database of Bureau van Dijk (BvD). I also collected, from the World Bank database, the annual

GDP growth rates and export demand for high-tech products for the relevant countries during the period of the nanotech R&D collaborations. Due to insufficient quantitative data on the collaborative dynamics of nanotech firms, I used survey instruments to generate interview and questionnaire data on geographical and functional proximity, governance mechanism, strength and duration of the partnership. The responses were then coded into ordinal observations. I conducted 30 interviews with top executives of nanotech firms and provided 97 questionnaires to senior administrators of nanotech R&D projects across 12 European countries.

Finally, I incorporated the legal origin index developed by La Porta *et al*., (1999); and subsequently modified by Beck *et al*., (2003); Spamann, (2009); and Cooray, (2011). The legal origins index represents the political structure and legal adaptability of countries where collaborative partnerships in nanotech R&D projects took place. Therefore, my measurement for estimating the legal dynamic affecting the dimensions of nanotech R&D collaborations was based on the tenure of Supreme Court judges, judicial independence, and legal justification. Similarly, I adopted the national cultural dimension indexes proposed by Hofstede (1983; 1994) for all the collaborative partnerships in nanotech R&D projects in my dataset, using uncertainty avoidance and masculinity vs. femininity indexes to provide measures of societal attitude towards ambiguity and the level of public intolerance for feminine values. I then carried out ordinary least square (OLS) regressions to analyze my data and provide empirical tests of my research hypotheses.

2.3.2 Dependent variable(s)

The key variables of interest in my study are four dimensions of inter-firm relations, namely: partnership size; governance mechanism; the strength of value network, and; time-frame to secure a patent or develop a new product during collaboration in nanotech R&D projects. The main dependent or response variable in my study is the size of the cooperative partnerships; the number of total partners in a distinct nanotech R&D project. I also developed three other dependent variables to consider the other dimensions of collaboration in nanotech R&D projects. The second dependent variable is the type of organizational structure in the collaborative partnerships of nanotech R&D projects. This ranges from level 1 to 3, i.e. from centralized to distributive and then decentralized governance mechanisms. The third response variable is the time frame (i.e., the duration) of R&D collaboration, which I group into short-, medium- and long-term periods. The final dependent variable is the ordinal scale of the strength of value network in nanotech R&D projects. This is ranked from 1 to 6 and contains three groupings of weak, medium and strong level of interactions with suppliers, consumers, regulators, legal bodies, open innovations and academic institutions.

Table 2.1: Key Variables, Expected Relationships, and Brief Description

S/N	Variables	Effects	Description
1	Size of Partnership	+	The total number of partners in a collaborative R&D project.
2	Governance Mechanism	+	The type of organizational structure (coded 1-3 from centralized to distributive to decentralized).
3	Innovative Capacity	_	The number of patents held before the start of the nanotech R&D projects.
4	Geographical Proximity	+	The geographical nearness to industrial partners (coded 1-4 for international, national, regional, & local closeness.
5	Functional Proximity	+	Functional nearness to value networks, i.e. (1-4) no partnership, suppliers, customers and both.
6	Venture Capital Participation	+	A dummy variable for VC fund managers' participation in nanotech R&D projects (coded 1 and otherwise 0).
7	Masculinity(vs) Femininity	+	Cultural index of societal attitude towards feminine values.
8	Uncertainty Avoidance	_	Cultural index of tolerance for uncertainty and ambiguity.
9	Organizational Size	_	Dummy variable (1) for large firms and (0) for SMEs based on the total assets of nanotech R&D firms.
10	Technological Advancement	+	The country's average export demand for high-tech products in the period of R&D collaboration.
11	Academic Affiliation	+	A dummy variable: (1) for academic involvement in nanotech R&D projects and (0) for otherwise.
12	Economic Growth	+	The average rate of annual GDP growth during the period of R&D collaboration.
13	French Civil Law	_	Dummy variable for nanotech R&D projects that operate under the French Civil Law (1) and (0) otherwise
14	German Civil Law	_	Dummy variable for nanotech R&D projects that operate under the German Civil Law (1) and (0) otherwise
15	Scandinavian Civil Law	_	Dummy variable for nanotech R&D projects that operate under the Scandinavian Civil Law (1) and (0) otherwise.
16	Biotechnology Industry	+	A dummy variable, (1) for nano-biotechnology type of R&D projects and (0) for otherwise.
17	ICT Industry	+	A dummy variable, (1) for nano-ICT type of R&D projects and (0) for otherwise.

18	Duration of Collaboration	+	The time frame of R&D collaboration (coded 1-3 short to medium to long term periods).
19	Strength of Value Network	+	The level of interactions with suppliers, customers, etc (coded from 1-6).

Source: Orbis & World Bank Databases and La Porta *et al.* (1999) & Hofstede (1994) Indexes.

2.3.3 Independent variable(s)

The independent variables remained, for the most part, the same in the four models used in my study. They were employed to determine the factors that influence the dimensions of collaborative partnerships in nanotech R&D projects, based on my theoretical framework. The independent variables help explain the variations in the dimensions of collaborative partnerships in nanotech R&D projects; they include: the geographical & functional proximity (coded 1-4 from nearness to industrial partners and value networks); legal origins (dummies for French, German and Scandinavian Civil Law, excluding the English Common Law as the base); Hofstede's national cultural dimension indexes (Uncertainty Avoidance & Masculinity vs Femininity); average annual GDP growth rate; the level of the export demand for high-tech products during the period of the R&D collaborations; existing innovative capacity (the number of patents held by the nanotech R&D organisation before start of the collaborative partnerships); a dummy variable for VC fund manager's participation in nanotech R&D projects; . Table *2.1* lists and describes most of the key variables and their expected relationship with the observed variable in model *1*.

2.3.4 Control variable(s)

I control for the organizational size of the nanotech firms based on the total assets of nanotech R&D organisations collected form Orbis database. Also, I control for academic and industrial (Bio-tech and ICT) affiliations using dummy variables (1) to represent those Nanotech R&D organizations which had these unique affiliations during collaboration. Controlling these variables help me better understand the effects of my independent variables on the observed variable.

2.3.5 Multiple regression models (OLS)

Since collaborative partnership can be observed in several ways, I developed two multiple regression models aimed at incorporating the different forms of collaboration in nanotech R&D projects. I adopted two different attributes of collaborative partnerships regarding the partner's size and governance mechanism of nanotech R&D projects. I used multiple linear regression models to derive OLS estimates that minimize the squared residuals of best fit. I specify my initial regression models for this research study in equation 1 below:

$$\gamma_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots + \beta_k X_{ik} + \varepsilon_i \qquad i = 1, 2\ldots n.$$

Where γ is the response variable for the i^{th} observation, which is the size of collaborative partnerships in all 97 R&D projects; β_0 is the constant or intercept that depicts the relationship that exists without the inputs of my explanatory variables. β_1 to β_k are the parameters and X_1 to X_k are the coefficients, while ε is the error term that describes the random element of the linear relationships between explanatory and response variables.

2.3.6 Logistic regression models

I formulated two logistic regression models that estimate the likelihood of my binary dependent output, based on several predictor variables. These are generalized linear models, which were used to analyze the variations in my dichotomous response variable about the independent variable. I specify my logistic regression models for this research study in equation 2 below:

$$\log\left(\frac{p(y=1)}{1-p}\right) = \beta_o + \beta_1 * x_{i1} + \beta_2 * x_{i2} + \cdots + \beta_k * x_{ik} \quad i = 1 \ldots k$$

Where logit (p/1-p) is the probability of the presence of long-term duration or strong value network and is transformed into the logged odds for the i^{th} observation as the duration and strength of collaborative partnerships in all 30 R&D organizations. y is a binary response variable. $y_i = 1$ if the duration is long-term or strength is strong; $y_i = 0$ if otherwise. $x = (x_1, x_2, \ldots, x_k)$ is the set of explanatory variables. x_i is the observed value of the explanatory variables for observation i.

2.4 Results

The empirical findings of my regression models are presented below in this sub-section. Descriptive statistics and the correlation matrix are presented in *Table 2.2*, and the multiple (models 1&2) and logistic (models 3&4) regression models are presented in *Table 2.3*.

2.4.1 Descriptive statistics

Table 2.2 provides the mean, standard deviation and correlation matrix of my study. Of particular importance are the means of GDP growth and innovative capacity, which are (70.66667) & (632.9667) respectively. The standard deviation of German Civil Law and Biotechnology Industry are quite peculiar in their size.

2.4.2 Inferential statistics

In *model 1*, I concentrated on the factors that influence the sizes of partnerships among nanotech R&D organizations. I used the total number of partners involved in the R&D projects that lead to new product development. I find that a high geographical closeness between nanotech R&D collaborative partners positively influences the total amount of partners, despite the limited nanotech specialists and clusters within a local region. Effective R&D collaborations among nanotech firms are dependent on highly skilled scientists who operate on very complex and expensive scientific instruments that require a high level of geographical proximity to achieve innovative productivity within a specified period of time. Also, I find that a high functional closeness in inter-firm relations positively influences the number of partners in nanotech R&D projects, due to the extra effort employed by senior administrators to establish useful forms of interaction, which reduces the communication distance.

Furthermore, my results show that, in countries with a high level of intolerance for ambiguous commercial ventures, there are a low number of total partners in nanotech R&D projects. Likewise, where the national culture of countries is that masculine values heavily dominate over feminine ones, there are usually fewer partners involved in nanotech R&D projects.

Table 2.2: Descriptive statistics and correlation matrix

	Variables	Mean	Std. Dev	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Organisational Size	2.333333	0.6064784	1																		
2	GDP Growth	70.66667	14.98121	0.3901	1																	
3	Uncertainty Avoidance	39.77776	12.99907	-0.1774	-0.3416	1																
4	Masculinity vs Femininity	55.44443	22.82255	-0.1656	0.0364	-0.0301	1															
5	French Civil Law	59.26667	21.86941	-0.4959	-0.6571	0.7624	0.3658	1														
6	German Civil Law	1.481611	4.448208	0.1718	-0.0589	-0.1811	0.1459	0.0038	1													
7	Scandavian Civil Law	5.73333	2.531639	-0.4836	-0.0291	-0.1426	0.3612	0.0404	-0.0424	1												
8	Technological Advancement	0.534185	1.445741	-0.3301	-0.0864	0.6226	-0.1388	0.3449	-0.1334	-0.0196	1											
9	Innovative Capacity	6.329667	2.223098	0.2496	0.0516	-0.193	0.0938	-0.0761	0.9531	-0.0411	-0.1487	1										
10	Geographical Proximity	3.77776	0.4660916	-0.1741	-0.1615	0.1111	-0.1649	0.1989	0.1805	-0.2137	-0.156	0.0998	1									
11	Functional Proximity	3.33333	0.8022956	0.3237	-0.1888	0.0006	0.1697	0.0143	0.2243	0.2332	-0.0524	0.1996	-0.2425	1								
12	Venture Capital Participation	0.166667	0.379049	-0.1741	0.4543	-0.2957	0.0195	-0.3838	0.4675	0.0001	-0.2052	0.5093	-0.2222	-0.0808	1							
13	Academic Affiliation	0.777776	0.4660916	0.0316	0.1448	0.2267	0.2779	0.1124	-0.3605	-0.0388	0.1135	-0.304	0.0605	0.0147	-0.3026	1						
14	Biotechology Industry	2.239005	9.544838	0.1933	0.2933	-0.1661	0.0999	-0.2663	0.0145	-0.0939	-0.0833	0.1481	-0.2475	-0.1554	0.3088	0.1342	1					
15	I.C.T. Industry	4.885833	1.262201	0.1367	0.1901	-0.0065	0.3271	-0.1944	0.0463	0.2521	-0.2337	0.1958	-0.3541	0.2395	0.0474	0.3489	0.6211	1				
16	Size of Partnership	9.252442	15.01211	0.3488	-0.2582	0.1222	0.0727	0.0443	-0.0937	-0.1814	0.0058	0.0424	0.3021	0.0191	0.3511	0.1087	-0.0923	0.1162	1			
17	Governance Mechanism	1.333333	0.894971	0.0573	0.1933	-0.1839	-0.1051	0.0101	0.0683	0.0249	0.0112	0.3591	0.0579	-0.0081	-0.0104	0.1985	0.1765	0.0046	0.0856	1		
18	Duration of Collaboration	1.953941	3.135495	0.0117	-0.6232	0.5456	0.0121	0.1164	0.0504	0.0129	0.0885	0.0984	0.5283	0.2478	0.0165	0.0308	-0.1211	-0.2034	0.0901	0.0414	1	
19	Strenth of Value Network	2.214776	1.017671	0.0767	0.0557	0.0882	-0.1185	0.8783	0.0439	0.0027	0.0502	0.1745	-0.0913	0.0621	0.0553	0.2677	0.0314	0.0052	0.1186	0.0159	-0.2853	1

The table shows the mean, standard deviation and correlation matrix of model 1.

Regulatory barriers, as well as low female participation in science and technology, are possible reasons for these cultural effects on the size of collaborative partnerships in nanotech R&D projects. Also, my results show that the economic expansion of a country enhances the sizes of collaborative partnerships in nanotech R&D projects, due to the additional sources of funds available for R&D expenditure. As expected, a high GDP growth positively influences the number of total partners in collaborative nanotech R&D projects. Similarly, an active VC fund manager's participation in the strategic activities of nanotech firms significantly adds to the sizes of collaborative partnerships; I believe this is in order to monitor and supervise the R&D projects so that innovative performance is attained as early as possible.

Nevertheless, there was weak support for some findings, notably the idea that countries with a legal origin in French Civil Law thwart more collaborative partnerships in nanotech R&D projects, compared with English Common Law, as a result of their rigid labor laws (La Porta *et al.,* 1999). Larger nanotech firms are capable of collaborating with more partners in an R&D project, compared with their SME counterparts, because they have greater financial resources and better human capital (Zheng *et al.*, 2014).

Table 2.3: Multiple & Logistic Regression Coefficients

	(Model 1) Size of Total Partnership	**(Model 2)** Governance Mechanism	**(Model 3)** Duration of Collaboration	**(Model 4)** Strength of Partnership
Geographical Proximity	0.155*** (6.02)	-0.135 (-1.63)	-0.851* (-5.44)	0.00981** (6.30)
Functional Proximity	0.394** (7.74)	-0.0465* (-3.52)	0.212* (4.99)	0.512* (5.24)
French Civil Law	-0.0249* (-3.28)	-0.103*** (-8.96)	-0.000169 (-1.67)	-0.00816** (-6.19)
German Civil Law	-0.0676 (-1.36)	-0.603** (-3.86)	-0.116 (-1.22)	-0.433 (-2.17)
Scandinavian Civil Law	-0.0244 (-2.10)	-0.0701 (-1.39)	-0.240** (-6.52)	-0.108 (-1.92)
Uncertainty Avoidance	-0.0201** (-5.53)	-0.0474*** (-4.86)	-0.157*** (-14.82)	-0.276** (-8.29)
Masculine v Femininity	-0.0542*** (-8.10)	-0.0639*** (-4.76)	-0.364*** (-16.15)	-0.545** (-8.41)
GDP Growth	0.0692*** (8.89)	0.0674* (3.08)	0.402*** (15.76)	0.584** (8.48)
Organizational Size	-0.0189* (-2.92)	-0.133** (-3.52)	-0.353*** (-14.71)	0.628** (8.67)
VC Participation	0.398**	-0.00825	-0.00189*	0.511

	(4.21)	(-2.25)	(-2.69)	(2.05)
Innovative Capacity	-0.00131*	-0.00163**	-0.00526*	0.0863**
	(-2.83)	(-4.22)	(-2.59)	(6.47)
High-Tech Advance	0.248*	0.0948*	-0.0713*	0.171**
	(3.13)	(2.57)	(-3.46)	(3.66)
Academic Affiliation	2.065*	0.635**		0.822*
	(2.95)	(4.02)		(5.28)
Biotechnology Industry	0.0637	0.303*	0.738**	0.110**
	(2.00)	(2.44)	(11.38)	(4.40)
ICT Industry	-0.00373	0.0367*	-0.0510**	0.0165
	(-1.28)	(2.45)	(-7.62)	(2.09)
Constant	4.393***	6.349***	32.25***	14.29**
	(8.04)	(6.80)	(18.96)	(5.02)
No. of Observation	97	97	30	30
Adjusted R2	0.85	0.80		
Pseudo R2			0.89	0.87

*Multiple and logistic regression coefficients for 4 models. The significance is ***1%, **5% &*10%.*

In *model 2*, I focused on the factors that affect the types of organizational structure in inter-firm collaborations of nanotech R&D projects across Europe. The main variable of interest is the kind of governance mechanism among partners in the R&D projects. I looked intensely at the method of control among collaborative partners (whether it was a decentralized, distributed or centralized system of governance) and how it was affected by external factors such as legal origin, cultural dimensions and geographical proximity of nanotech firms, while controlling for organizational size, academic affiliation and innovative capacity. My results show that legal origins significantly affect the governance mechanisms of collaborative partnerships in nanotech R&D projects. I find that nanotech firms that carry out their collaborative R&D projects in countries with French and German Civil Law origins have centralized governance mechanisms, compared with English Common Law origin, because of the need to tightly control the activities of their partners to adhere to stringent regulatory policies.

Moreover, my results show that a country's cultural attitudes concerning uncertainty and feminine values affect the way nanotech R&D projects are managed. A high intolerance for ambiguous nanotech R&D projects within a society brings about centralized governance mechanisms, which lead to less innovative outcomes. Likewise, a dominant masculine culture within a society means that nanotech R&D projects tend to have centralized governance mechanisms that seek to achieve organizational objectives at the earliest possible time frame. Also, my results show that economic growth has a positive but weak impact on the governance mechanisms in collaborative partnerships of nanotech R&D projects. Here I argue that the availability of economic opportunities during boom times creates a tendency towards decentralized or distributed systems of governance, which foster innovative engagement among collaborative partnerships. Similarly, the export demand for high-tech products represents a form of a nation's technological advancement: I find that, when it is high, it negatively affects the nature of the governance mechanisms employed by collaborative partnerships in nanotech R&D projects. I also find that a high innovative capacity and a large organizational size both facilitate centralized governance mechanisms in the collaborative partnerships of nanotech R&D firms.

In *model 3*, I focused on the external factors that affect the durations of collaborative partnerships with nanotech R&D organizations. *Model 3* specifies the determinants of the period in which R&D cooperative engagements take place in only two periods, i.e. short- and medium-term versus long-term durations. My results show that the likelihood of a long-term inter-firm relationship in nanotech R&D projects is reliant on the legal origins, cultural values, economic growth, organisational size and industry affiliations. Specifically, nanotech R&D projects that are carried out in countries with an origin in Scandinavian Civil Law are more likely to be shorter duration, compared with their counterparts in English Common Law countries. Also, a high intolerance for ambiguous R&D projects most likely reduces the duration of collaborative partnerships among nanotech firms. Likewise, a dominant masculine culture within a society increases the likelihood of short-term R&D collaboration. Also, a high GDP growth rate is more likely to have a positive effect on the time spent in nanotech collaborations, as funding from R&D expenditure increases. As funding prospects are enhanced during a period of economic expansion, underperforming nanotech R&D projects could continue to receive the financial resources needed to fund such operations, and thereby extend the duration and increase the manpower available to ensure that a new product is developed and/or patent secured. Finally, I find that organizational size and industry affiliations influence the duration of R&D collaborations among nanotech firms. The larger the organizational size, the more likely there were short- and medium-term R&D collaborations. Finally, nanotech R&D projects with biotechnology firms take longer, while those with information and communication companies are more likely to take a shorter time frame.

In *model 4*, I focused on external determinants of the strengths of value networks in inter-firm collaborative partnerships of nanotech R&D projects. I find that geographical proximity, legal origins, cultural values, economic growth, organizational size, innovative capacity, technology advancement and industry affiliations all significantly influence the strengths of value networks in nanotech collaborative partnerships. Specifically, I find that a high geographical proximity (not strongly but significantly) is likely to positively affect the strengths of the value networks of nanotech R&D projects. Also, countries with French Civil Law origins are likely to weaken the value networks of nanotech R&D projects, compared with those with legal origins in English Common Law countries. Likewise, countries where uncertainty avoidance is high, and where masculine values prevail over feminine values, are more likely to have a weaker value network. Also, a high economic growth rate and a high export demand for technologically advanced products are likely to have a positive impact on the strengths of value networks in nanotech R&D projects. Finally, a high innovative capacity, large nanotech organization, and affiliation to biotechnology industry are likely to have a positive effect on the strengths of value networks in R&D collaborations.

2.5 Discussion and Implications

In this section, I identify possible opportunities and challenges for policy-makers and organizational strategists to exploit or guard against, with the objective of enhancing various dimensions of collaborative partnerships within the nanotech R&D projects.

2.5.1 Legal origins

Countries with French Civil Law Origins have a less rigorous legal system (La Porta *et al*., 1999). Nanotechnology is an emerging technology that has few laws regulating its industry. The French and German legal systems provide a lesser degree of flexibility for securing patents and higher level of predictability for estimating litigation outcomes. This makes it less appealing to nanotech R&D collaborative partnerships, because there are lots of regulations that either restrict the nature and scale of research exploration and commercial exploitation or that could pose a huge threat and raise the possibility of large losses – unlike the English legal system, where there is an inherent rule to have minimum standards of care.

The impact of nanoscience and nanotechnologies has been keenly highlighted by prominent individuals, interest groups (Royal Society and Royal Academy of Engineering) and even movies ("grey goo"), so as to promote thorough risk assessments and further regulatory activities, and ensure that a high level of ethical standards are employed during commercial development. These assurances have significantly reduced the British public's concerns about the ambiguities in nanoscience and nanotechnology. Therefore, it is imperative for nanotech firms in countries with an English Common Law origin to take into consideration the additional cost required to make risk assessments about their R&D projects publicly available, in order to enhance public awareness and reduce the general intolerance for uncertainties associated with nanotechnology.

2.5.2 Proximity

Despite the advancements in information and communication technologies (ICT), as well as the free movement of capital and labor across Europe, geographical and functional closeness still matters greatly in determining the size, command chain, strength and duration of collaborative partnerships in nanotech R&D projects. Spatial nearness among scientists negatively influences the partnership size, but positively affects the organizational structure of collaborative partnerships in nanotech R&D projects (Knoben and Oerlemans, 2006).

Nanotechnology is an interdisciplinary field that requires a great deal of physical closeness among R&D partners, who use very complex instruments to develop innovative products and services through a decentralized system of governance that minimizes contingency risks (Steinmo and Rasmussen, 2016). The lack of a concentration of nanotechnology experts within a local scientific community in the past has created a need for international collaborations with a distributive organizational structure, in spite of the drawbacks from their geographical closeness (Kabo *et al*., 2014).

Functional proximity relates to the nearness of partners regarding their basic operations and areas of specialty during the R&D collaborations. The quality of the value network is strengthened when there was a substantial division of labor and clearly defined roles, which enabled partners to uniquely contribute to the nanotech R&D project within a strategic time frame to attain specified commercial objectives. A strong value network and long-term R&D collaboration among nanotech firms are more likely to be negatively affected if there are high levels of functional closeness within the partnership. I argue that the absence of institutional diversity impedes the overall ability of the collaborative partnership to maintain a steady development of new and innovative products or secure exclusive rights to intellectual property.

2.5.3 Cultural dimensions

The level of tolerance for uncertainty within a nation reveals their cultural attitude towards risks and ambiguity (Sriwindono and Yahya, 2012). A country with a high uncertainty avoidance index is more likely to have rigid belief systems that are intolerant of unorthodox and risky behaviors, because the majority of people with such cultural values are sensitive to, and feel uncomfortable with, unstructured or changeable environments. However, a low uncertainty avoidance index evinces that members of a society are more likely to be forbearing towards ambiguous or uncertain R&D ventures, because they are entrepreneurial in nature and are likely to feel comfortable in risky and less structured environments. In these countries, nanotech R&D project managers can take advantage of the politically active and informed populations by making quick decisions that exploit innovative concepts.

Feminine values are another important cultural trait to seriously consider, as this trait affects the dimensions of collaborative partnerships in nanotech R&D projects. A high proportion of female involvement in science and technology within a country would more likely increase the strength of value networks and reduce the time period of collaborative partnerships in nanotech R&D projects. In contrast, a more dominant male presence usually leads to ego-oriented inter-firm relationships that promote fierce competition and focus on profit maximization, irrespective of the impact on the external environment. Cultural values do not easily change in the short run and are usually passed from one generation to another, so it is expedient for policy-makers and corporate strategists interested in nanotech R&D collaborations to understand the possible implications and predictable behaviors relating to risk tolerance, procedural controls, and adherence to norms within a community that they operate in, so as to promote discussions that alleviate unproven claims, improve negotiating processes, and reduce litigation costs (Hong, Heikkinen, and Blomqvist, 2010).

2.5.4 Economic growth

Periods of economic growth positively affect the size, mechanism, strength and timeframe of collaborative partnerships in nanotech R&D projects, as a result of the availability of several funding prospects, the prevalence of commercial opportunities, and the rise in labor participation. In knowledge-based economies, the expansion of economic activities usually leads to a rise in R&D expenditures. Most universities normally obtain huge funds from research councils and industry partners to finance their R&D projects, with the aim of building innovation centers and fostering regional economic development (This corresponds with the findings of Bilbao-Osorio and Rodriguez-Pose, 2004; Guerrero, Cunningham, and Urbano, 2015).

The university-industry collaborative partnership is a key ingredient that stimulates productivity in innovative ventures (Jong and Slavova, 2014) and accelerates the growth of economic activities in advanced countries. An increase in the external R&D activities of high tech firms has resulted in the rapid rise of inter-organizational relationships, which lead to patent licensing agreements and the development and production of new products. The commercialization of R&D activities via university-industry collaborative partnerships has brought not only economic development but also the technological advancement of nations, due to the international demand for their high-tech products, which are usually emerging or disruptive know-how. Having exclusive rights to an innovative product in the form of a patent provides nanotech firms with the required protection for their intellectual property and encourages more R&D projects in the future.

2.5.5 Technological advancement

As a result of globalization, many countries have been able to unlock localized industries by taking advantage of new and existing export opportunities for high-tech products and services around the world (Mehta *et al*., 2012). World trade organization has alleviated most barriers and challenges in international commerce, as advanced nations and large corporations are able to attract high-skilled labor and sophisticated investments into emerging and disruptive industries to provide technologically-advanced products and services for worldwide consumption. The export demand for high-tech products evinces the level of technological advancement in a country. Most MNCs have their internal R&D capabilities at their headquarters, and many external R&D projects are organized in their home country. Nanotech firms that operate in advanced technological nations are more likely to sell their newly developed innovative products to international markets. They are also more likely to spend less time in collaboration, due to their centralized governance mechanisms and comprehensive value networks.

2.6 Conclusion

Collaboration in nanotech R&D projects usually involves large funds and expertise, which divert managerial resources away from internal R&D projects. Institutionalizing collaborative partnerships is extremely challenging, because R&D projects demand new organizational structures and procedures that harness available resources to achieve set objectives. My study shows that large nanotech R&D organizations have fewer industrial partners who spend less time to develop new products, due to their strong value networks and centralized systems of governance in collaborative partnerships. Meanwhile, smaller nanotech R&D firms require more time and a greater number of industrial partners to develop new products, as a result of their willingness to impose a decentralized organizational structure in R&D collaborative partnerships.

As a discontinuous innovation-based technology, nanotechnology has few laws that regulate its industry. It requires highly skilled scientists from different disciplines to work in close proximity and operate complex instruments to create innovative new products within a specified period of time. Nanotechnology is an interdisciplinary field that requires a great deal of physical closeness among R&D partners, despite the advancements in ICT as well as the free movement of capital and labor across Europe. Globalisation has helped many countries to unlock localized industries, by taking advantage of new and existing export opportunities for high-tech products across the globe. Advanced nations and large corporations are able to attract high skilled labor and sophisticated investments into emerging and disruptive industries to provide technologically advanced products and services for worldwide consumption. The European Commission has briskly funded inter-firm R&D collaboration through its Framework Programme for research and technological development.

Certain legal systems, which provide both a greater level of flexibility for securing patents and a higher level of predictability for estimating litigation outcomes, are likely to be more appealing to nanotech R&D project managers, because there is little regulation restricting the nature and scale of research exploration and commercial exploitation or that could pose a huge threat and the possibility of large losses. However, a collaborative partnership among nanotech organizations could be employed as a market entry corporate strategy into tightly controlled industries to circumvent regulatory constraints. In countries that seem to have a low level of uncertainty avoidance, most members of their public are more likely to be tolerant towards ambiguous or uncertain R&D ventures because of their entrepreneurial mindset, which is at ease with risky and unstructured environments. Culture doesn't change easily and is usually inter-generational, providing an understanding of the possible consequences and predictable behaviors relating to risk tolerance, procedural controls, and adherence to norms within a community – suggesting a need to encourage public debate and general awareness.

Countries with high uncertainty avoidance index are more likely to have rigid belief systems that are intolerant of unconventional and hazardous behaviors, because the majority of the population feels anxious about unpredictable environments. A low uncertainty avoidance index evinces that members of the public are more likely to be tolerant towards ambiguous or uncertain R&D ventures because of their entrepreneurial mindset which is at ease with risky and unstructured environments. Also, a high proportion of female involvement in science and technology within a country would likely increase the strength of value networks and reduce the period of collaborative partnerships in nanotech R&D projects.

Universities involved in discontinuous innovation-based R&D projects have specialized interdisciplinary centers, which are capable of collaborating with more industrial partners because of their access to additional financing. Patents and other intellectual property should be used to meet the needs of low-end and prospective customers. Also, academic institutions are now benefiting from the legitimate financial considerations of supplementing patents with publications. The existence of VC funding in nanotech R&D projects indicates that there are significant commercial opportunities available, and that entrepreneurial prowess is prevalent in such collaborative partnerships. There are other significant variables, not included in this model, that influence the ability of nanotech companies to collaborate with a large number of industrial partners. Certain key features of a company – such as its age, size, market position, and financial status – could be useful tools for predicting the propensity to enter successful collaborative partnerships. A much larger sample size, incorporating more countries in which nanotech companies operate, would provide useful insights into the legal and cultural determinants of the level, size, and timing of collaborative partnerships.

Chapter 3: Internal Intricacies and Innovative Performance of Collaborative Partnerships in Nanotechnology R&D Organisations

3.1 Introduction

As an engine for economic growth, job creation and radical innovation in knowledge-based economies (Protogerou et al., 2017); high-tech firms play an important role in establishing collaborative partnerships with universities (Caloghirou et al., 2001) in order to develop a portfolio of innovative products and pioneering systems (Nieto and Santamaria, 2007) which thrives despite the swift changes in the socio-economic and technological environments (Baranenko, et al., 2014) that requires shorter product life cycles as a result of intense global competition (Deeds, DeCarolis and Coombs, 2000). Through the Framework Programme (FP) for research funding, the European Commission has vigorously financed inter-firm R&D projects (Roediger-Schluga and Barber, 2006; Paier and Scherngell, 2011) to promote innovative performance in high-tech firms so as to enhance their global competitiveness (Scherngell and Lata, 2013). Globalization of science, technology and commerce has rapidly advanced human endeavour; making it essential for high-tech firms to continually improve their product lines and manufacturing processes to meet the ever-increasing stakeholder expectations (Lo et al., 2011). Consequently, the internationalization of economic activities and consumer preferences cause high-tech firms to become more strategic in pooling both internal and external R&D resources together through offshore outsourcing (Bertrand and Mol, 2013) or local collaborative networks (Bresciani and Ferraris, 2014); with the objective of producing multi-technological goods which attract huge export demand from international markets (Narula, 2004).

Previous organisational studies have shown that knowledge creation and the assimilation of information through universities is significant for industrial innovation, as high-tech firms are well-known to develop and accumulate vital technological capabilities based on formal and informal modes of organisational learning (Belderbos, Carree and Lokshin, 2004; Czarnitzki, Ebersberger and Fier, 2007; Maietta, 2015; Thoma, 2017). The absorptive capacity of high-tech firms is their ability to access sources of valuable information and develop contractual relationships that could be transformed into a set of exclusive rights on intellectual property which enriches the prospect of their survival; increases the likelihood of a sustainable stream of revenue; and fosters productivity and profitable expansion into new markets (Mowery, 2011). The increasingly complex, extremely expensive and highly interdisciplinary features of modern scientific activities have resulted in the rise of inter-organisational R&D collaboration (Teece, 1986); as a cost effective means for high-tech firms to access and exchange new knowledge, secure additional human capital, develop innovative methods, improve value network and enter into heavily regulated markets (Matt, Robin and Wolff, 2012); in order to benefit from the diversification of risks, transfer of scientific knowledge, enhanced market competitiveness, greater return on investment, better rate of survival, improved reputational status and brand recognition.

Nanotech R&D collaborations embrace a multipurpose application of science that has radical innovations in processes, disruptive impact on existing industries and transformative effect in societies. In this research study, I concentrated on the key performance indicators of inter-firm R&D collaborations in nanotech industries across Europe; as nanotechnology is a highly intensive R&D science-based cluster (Mangematin and Errabi, 2012) with complex interdisciplinary characteristics (Schummer, 2004; Rijnsoever and Hessels, 2011) which promote multiple knowledge exchanges between scientists from different socio-economic backgrounds (Katz, 1994; Kostoff et al., 2006) employed in multi-faceted research organizations (Heinze, 2004; Cunningham and Werker, 2012) in both public and private sectors (Miyazaki and Islam, 2007) and across internationally regulated markets (Romig Jr. et al., 2007). The antecedents to the successful commercialization of European nanotech R&D projects has been barely been covered in the literature (von Raesfeld et al., 2012); hence, why I investigated the main internal factors which affects the innovative performance of nanotech firms across Europe; as they actively participate in a voluntary cooperative arrangement that is likely to facilitate the development of new innovative products and/or services through the exchange of technology and sharing of expertise with university partners (Huang and Chen, 2016).

The motivation of this study was dependent on my inquisitiveness in understanding the extent to which factors under management control influences the different types of innovative performance in nanotech R&D projects across Europe so as to provide corporate strategists with valuable information on the internal intricacies which expedite creativity, productivity and profitability in nanotech firms involved in R&D collaborations. My study focuses on evaluating the main internal determinants of the amount of patents, quality of new product development and level of profitability in collaborative partnerships of nanotech R&D projects across Europe. I looked intensely at the human capital, financial resources and inventive assets of nanotech firms; while controlling for their previous cooperative experience, duration of collaboration and VC participation. The main research question for my study is how do internal factors affect the innovative performance of nanotech R&D projects across Europe? My research objective is to provide nanotech managers of R&D projects with valuable knowledge on how the structural internal dynamics of collaborative partnerships affects the attainment of patents, new product development and profitability.

I employed multiple regression analysis to evaluate the relationship between successful nanotech R&D projects and key performance indicator variables. I collected secondary data from Orbis and Zephyr databases as well as primary data from survey instruments in order to observe the internal dynamics of collaborative partnerships in nanotech R&D projects. The key contribution of my study is the evaluation of the impact of financial status, value network, organisational structure, absorptive capacity and partnership size on the innovative performance of nanotech R&D projects engaged in collaborative partnerships in Europe. I then conclude by ascertaining the core internal dynamics which corporate strategists and R&D project managers need to be aware of, so as to enhance a productive inter-firm collaboration that increases the competitive advantage of high-tech firm in the EU. More so, I conclude that since nanotech R&D activities are inherently complex and at times with uncertain outcomes, the onus on top managers of high-tech organisations is to design simpler and flexible governance mechanisms which builds the firm’s capacity to retain and integrate new knowledge and innovative techniques into existing corporate systems during periods of high financial positioning with the intention of maximizing technological productivity. In the following sections, I would present the theoretical framework, research methodology, empirical findings, discussion, and the conclusion of this research study.

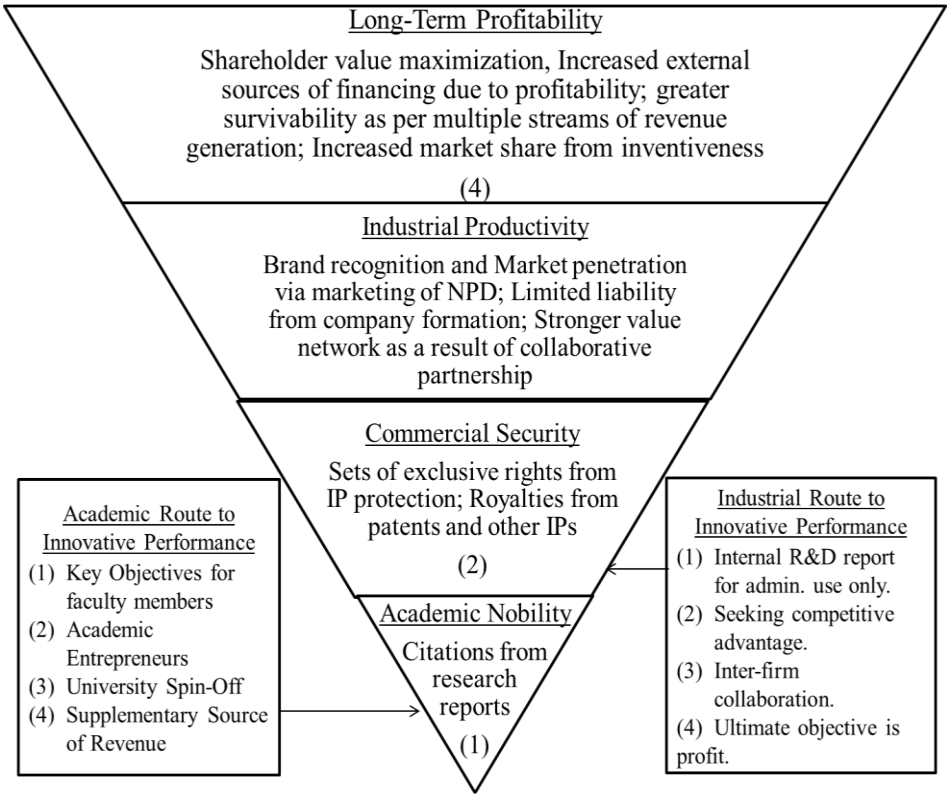
3.2 Theoretical Framework

3.2.1 Scientific productivity through Research Collaborations

The convention among research communities for some years now has been collaboration due to the increasingly complex, very expensive and highly interdisciplinary features of modern scientific endeavour (Teece, 1986). Effective collaboration in science and technology is the meaningful cooperation of researchers in achieving a collective goal of creating and disseminating new scientific knowledge (Fiaz, 2013); which could be developed among individual researchers such as department/faculty groups; across public/private sectors such as university and industry cooperation; and between countries such as multi-national interdisciplinary research association (Ponomariov, 2013). It can be argued that collaboration among individual scientists from different research societies implicitly confirms and explicitly reinforces their belief in the virtues of universal validity as it fosters consensus and facilitates diffusion within the global scientific community (Lee and Bozeman, 2005). The prerequisite for a global diffusion of scientific knowledge is prevalent in the belief in collective rationality, wider dissemination, and intensive collaboration (Schott, 1991). According to Katz (1994), the factors which promote collaboration among individuals within scientific communities are: changes in levels of funding; desire for visibility and recognition among researchers; increasing demand for the rationalisation of scientific manpower; rapid specialisation in science; and growing proliferation of science. Lee and Bozeman (2005) observes that the incentive for research collaborations among individual scientists are the rising costs of conducting experimental science; the availability of quick and avoidable transportation & communication facilities; the proliferation of scientific communities around the globe; the politicizing of research activities; and the strong demand for specialisation within the fields of science.

The growth of scientific clusters in universities has led to the geographical concentration of research activities and the recurrent interactions between cluster members (Mangematin and Errabi, 2012); policy initiatives which seek to foster research collaboration in science and technology within socio-economic regions (Vecchiato and Roveda, 2014) have created several benefits such as the transfer of new knowledge, skills and techniques; the cross-fertilisation of revolutionary concepts and innovative ideas; the provision of intellectual companionship and proprietary; and enhancing of the prominence of research work and technological advancement. Research collaboration is used not only as a robust predictor of publishing productivity but also as an important metrics for assessing the scientific performance of research organisations (Kostoff et al., 2007). Previous studies have shown that the amount of co-authorships in peer-review journals partially determine the extent to which valuable interaction among research entities could be measured (Smith, 1958).

Figure 3.1: Hierarchical Accomplishments in University and Industry R&D Collaborative Partnerships for High-Tech Invention



Source: This model was adopted from OECD's National Innovation Systems 1997 future research recommendations for measuring innovative performance of R&D projects

However, scientific productivity as a function of academic publications is profoundly different from industrial innovation because the former is primarily concerned with adding and diffusing new knowledge into the existing body of knowledge while the latter is more interested in adding to the streams of income from the exclusive rights of hoarding private information (Dietz and Bozeman, 2005). As a result of the commercialisation of academic research and the rise in academic entrepreneurship, some research activities have been geared towards building strong collaborative value networks that are organised to acquire intangible intellectual assets which could further be developed into innovative products that could likely disrupt existing market structures or improve inefficient industrial systems; but ultimately try to generate an additional source of revenue for all stakeholders in a knowledge economy (Siegel and Wright, 2015).

Figure 3.1 depicts the phases in which new knowledge is produced and commercially secured, then further developed into innovative product/service for market consumption. The scientific productivity to technological profitability model describes the hierarchical success levels of inter-organisational R&D collaborations. The active interaction between academic scientists and industrial researchers in developing innovative products in high-tech industries is critical to building comparative advantage in knowledge-based economy. The growth of academic entrepreneurs has led to the commercialization of novel concepts derived from scientific endeavours.

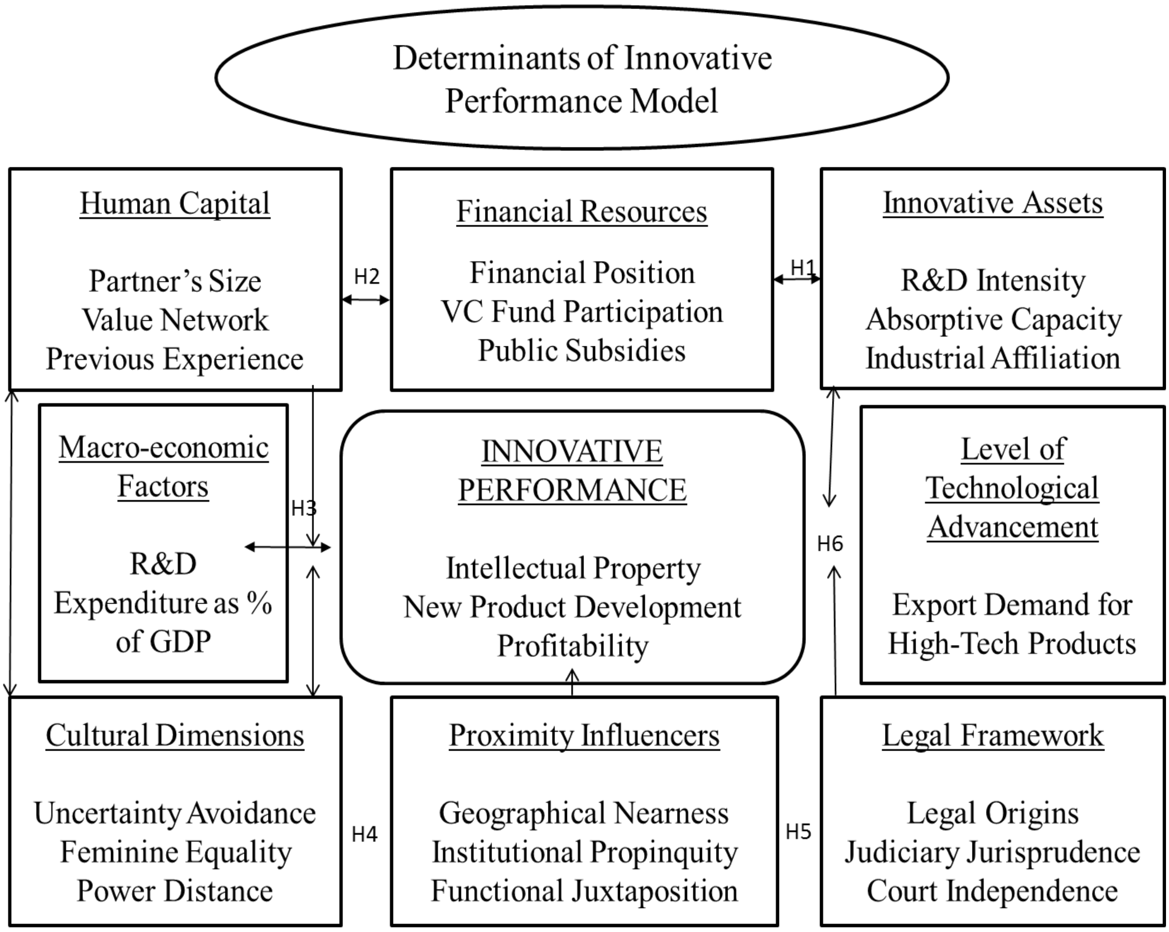
3.2.2 Innovative Performance from Collaborative Partnerships in High-Tech Industries

Many government policies have strengthened the collaboration among university and industry in order to facilitate the transfer of technology and stimulate economic development (D'Este and Patel, 2007). These R&D cooperative partnerships usually produce innovative concepts which are intellectually protected by the European Patent Office since its inception in 1973 and by the Bayh-Dole Act of 1980 in the US, as it provides the legal basis for university scientists' to obtain sets of exclusive rights for their inventions (Poyago-Theotoky et al., 2002; LaFlame, 2009). Institutionalizing cooperative engagement is quite challenging in high-tech industries due to the demand for new organisational structures, procedures and strategies (Todeva and Knoke, 2005). The survivability and success of companies operating in high-tech industries with highly complex and knowledge-intensive environment depends considerably more on collaboration rather than competition (Barbolla and Corredera, 2009). University-industry partnership accelerates learning and innovation in R&D organisations (Carayannis, 1999), for the purpose of sharing knowledge and other valuable resources in order to enhance existing or create new processes, products or services (Un and Asakawa 2015). Despite the numerous benefits, the major obstacle in this inter-organisational relationship is the convergence of the key objective of academia which is to proliferate and exchange knowledge through open sources and those of the industry which is to acquire and protect proprietary information for commercial profits (Steinmo, 2015). The conflict of interests in university-industry partnerships; as Ponds et al. (2007) observe is that scientists are keen on openly sharing scientific knowledge for wider dissemination and universal citation while corporate managers are eager to closely protect innovative information for commercial gains and competitive advantage.

Patents provide reasonable inducements for scientists to embark on commercially profitable R&D projects which could be converted into strategic capabilities and core competencies for high-tech firms in knowledge-based economies (Huang and Chen, 2016). These technological innovations upon been patented could be made known to the general public as per the security from the exclusive rights granted to the inventors. Also, high-tech firm managers are required to carefully evaluate the optimal strategy for securing trade secrets from internal R&D investments when acquiring new knowledge through collaborative partnerships, such that their competitive advantage is not diluted but enhanced (Torugsa et al., 2016).

Besides, the major contributors to innovation in young high-tech companies are their external network contacts for collaboration and the level of R&D outlay (Keizer et al., 2002). Usually, the burdens of and complexities in carrying out R&D activities facilitates the use of external networks by high-tech firms in order to cultivate complementary resources which overcome uncertainties related to new technology development and circumvent innovation barriers due to limited human and financial resources (Zeng et al., 2010). External networks are explored to supplement for the internal R&D deficiencies in high-tech firms; customarily when economies of scale and/or scope could be achieved through the integration of trailblazing conceptions and know-hows (Mancinelli and Mazzanti, 2009). Once exclusive rights to an invention are specified, then the development of new products/services and their ensuing profitability becomes the focal mission of managers in high-tech firms (Torugsa et al., 2016).

Figure 3.2: Internal (and External) Factors that influence the Innovative Performance of High-Tech Firms in Knowledge-based Economies



Analytical framework of the internal and external determinants of innovative performance

In *figure 3.2*, I constructed a model that identifies the internal as well as the external determinants of commercially successful technological innovations from R&D collaborative partnerships in high-tech industries. In this study, I focus on three internal determinants of innovative performance based on the factors of scientific production: human capital, financial resources, innovative assets and excluding natural reserves. Managers of high-tech firms should also be aware of the external environment in which they operate in, so as to, identify potential opportunities and minimize likely threats to the profitability of new products been developed through R&D collaborations. The external factors which affect the innovative productivity of high-tech firms are: macroeconomic conditions, technological advancement, cultural dimensions, legal framework and proximity concerns (Islam et al., 2018).

3.2.3 Human Capital Factor in Successful R&D Projects

3.2.3.1 Partner's Size

Rothwell and Dodgson (1991) argue that in an innovation process, small and medium-sized enterprises (SMEs) possess several behavioural advantages over large companies such as: efficient internal communication mechanisms, interactive & dynamic management systems and organisational flexibility in swiftly responding to external threats. Although, large firms enjoy some merits of their own such as: the ability to disseminate risk over a range of new products, ease in expanding operations to other regions and capability to fund long-term strategic R&D projects. When compared with large companies, SMEs are significantly unable to establish the most suitable external network of partners for collaboration. Kaufmann and Todtling (2002) observe that SMEs have smaller external relations than large companies which make them more confined to their local region because of the need to have direct interactions in tacit knowledge exchange. Large firms are far more likely to have cooperative relationship with the vertical partners (such as universities, research institutes and training centres) in their supply chain than SMEs. However, technology-driven SMEs are uniquely different in this regard.

The inability of SMEs to engage in vast cooperative partnerships outside their business relations is due to the small number of employees capable of initiating and preserving network links. As far as external network relations are concerned, SMEs are focused more on developing regional partnership than multinational corporations (MNCs). Lindsay and Hopkins (2010) assert that it is very problematic for MNCs to pursue speculative opportunities and/or mitigate unestablished threats posed by disruptive innovations due to their cultural and structural impediments. Zeng et al (2010) argue that the access SMEs have to external resources and expertise from their cooperative partnerships provides stimulus for innovation. Harris (2000) argue that MNCs are faced with the onus of creating an organisational culture that embraces diversity in order to harness fully the skills and talents of all their employees. Bjorkman et al (2007) observe that MNCs have competitive advantage from their superior ability to transfer and combine competencies across geographically dispersed entities. Todeva and Knoke (2005) argue that MNCs are networks of intra and inter-firm cooperation which covers national orders and industrial sectors.

H1: The larger a partner's size is in nanotech R&D collaboration, the greater the innovative performance the high-tech firm would experience.

3.2.3.2 Strength of Value Network

Allee (2008) observe that value network is a firm's ability to convert tangible and intangible assets such as employee know-how, internal structures, company reputation, and business relationships into negotiable forms of value. Value network is a grid of interactions which create real and artificial wealth through multifaceted vigorous relationships between members of an enterprise system. Analysing the value network of a company is a treasured channel through which important information on cooperative opportunities is received and in turn influences the behaviour and performance of collaborations with partners (Gulati, 1998). One of the most significant environmental influences of an organisation is the key internal activities and external contacts in their value network (Powell and Smith-Doerr, 1994). Management require collaboration within and across departments, organisations and industries to achieve key objectives of their firms (Bedwell et al., 2012). Building trust-based relationships is critical for converting internal and external firm resources into transactional assets for commercial purposes; and it is the foundational dynamic in knowledge based economies (Taug, 2004). Members within a value network make full use of all their available resources by developing roles which add more value to existing assets in order to maximize shareholder wealth. The future success of firms is mostly dependent on the efficiency of its management in transforming strong and dynamic relationships and their intangible assets into marketable products and services (Allee, 2008).) An indispensable factor which affects the likelihood of a high-tech firm innovating successfully is its ability to efficiently meet or exceed customer expectations through value networking (Christensen and Rosenbloom, 1995). Therefore, in order to effectively alter the cognizance of a challenging condition and organise a collective action plan to enforce any transformation, the unidentified interactive movement which powers organisational procedures should be observed to produce prognostic management information about the uncertainties associated with innovative performance.

H2: The stronger the value network in nanotech R&D collaborations, the higher the level of success of high-tech firms in securing a patent, developing new products which become very profitable.

3.2.3.3 Previous Collaborative Experience

Collaborative experience in R&D projects involves the accumulation of organisational knowledge through inter-firm relations with multiple sets of partners and from the repeated association with certain partners over a period of time. Bruneel et al., (2010) observe that the factors that mitigate the obstacles to fruitful collaborations are: past collaborative experience, inter-firm trust and comprehensive interactive channels. Hoang and Rothaermel (2010) conclude that the internal exploration proficiency permits firms to leverage their external exploitation experience successfully. Simonin (1997) asserts that for previous collaborative experience to have a positive effect on new R&D partnerships, organisational knowledge has to first be internally developed by the firm and then properly managed to contribute to successful future collaborative outcomes. Hoang and Rothaermel (2005) argue that based on the theory of organisational learning, past collaborative experience influence the innovative performance of high-tech firms. Therefore, it is very essential for the management of high-tech firms to put in place an organisational learning arrangement which converts previous and continuous R&D collaborative experiences into organisational knowledge that could then be applied in future cooperative engagements (Simonin, 1997).

H3: The longer the numbers of years in past R&D collaborative partnership coupled with an organisational learning structure which transforms firm's experience into know-how, the higher the level of innovative performance nanotech R&D projects enjoy.

3.2.3.4 Decentralised Organisational Structure

The governance mechanisms for robust collaborative partnerships in inter-firm R&D projects require a decentralised command system which oversees large amount of funds and organises vast number of human capital in specialised framework that stimulates useful innovative engagements among all players (Scandura, 2016). Institutionalizing collaborative partnerships are extremely challenging because R&D

projects demands new organisational structure and procedure which is able to harness available resources in achieving agreed objectives (Contractor and Lorange, 2002). Nanotechnology as an interdisciplinary field which requires a great deal of physical closeness among R&D partners using very complex instruments to develop innovative products and services through a decentralised system of governance which minimizes contingency risks (Steinmo and Rasmussen, 2016). The lack of a concentration of nanotechnology experts within a local scientific community in the past has created a situation where there is the need for international collaborations with a distributive organisational structure; in spite of the drawbacks from their geographical distance (Kabo et al., 2014). The geographical closeness positively influences the type of governance mechanism employed during an inter-firm collaborative partnership in nanotech R&D projects across Europe because developing a coherent organisational structure facilitates the attainment of initial objectives. The adoption of a decentralised chain of command in the organisational structure of collaborative partnership in nanotech R&D projects across borders are determined by a high level of geographical distance between actors involved, all other things being equal (Islam et al., 2018).

Likewise, legal origins significantly affect the governance mechanism of collaborative partnerships in nanotech R&D projects. Particularly, countries with English common law origins positively influence the organisational structure of cooperative arrangement towards a decentralised or distributed chain of command due to flexibility of its legal system and the adaptability of judge-made law. A country's cultural behaviours concerning tolerance for uncertainty & ambiguity and women's equality affects the way nanotech R&D projects are managed so as to ensure that new product development are successful. Islam et al. (2018) asserts that a positive but weak relationship exist between a nation's tolerance level for avoidance and the governance mechanism used to supervise and monitor nanotech R&D projects such that a high tolerance level increases the possibility of having a decentralised chain of command and thereby more innovative new products. Also, economic growth has a positive impact on the governance mechanisms in collaborative partnerships of nanotech R&D projects. The availability of economic opportunities during boom times provides the tendency for organisational structure with a decentralised or distributed system of governance which fosters innovative engagement among collaborative partnerships. The control structure of collaborative projects could take different forms but as Kogut (1991) suggests, it used be a platform where high-tech firms could explore business uncertainties and devise strategies to take advantage of opportunities in a fast growing and diverse market.

H4: The more decentralised and distributive system of governance in collaborative partnerships of nanotech R&D projects is, the greater the innovative performance.

3.2.4 Financial Indicators of the Innovative Performance of High-Tech Firms

3.2.4.1 VC Fund Participation

Venture capital (VC) could be defined as an independent, professionally managed, dedicated pools of capital that focus on equity or equity-related investments in privately held, high growth companies (Gompers and Lerner, 2001). Venture capital funds are a collective investment scheme used in making investments in various portfolio companies. A large portion of the global VC industry operations can be attributed to the entrepreneurial spirit prevalent in the United States. Also, the access OECD countries have to efficient capital markets, skilled workforce, effective intellectual property protection and sophisticated research facilities enhance their VC activities and performance (Djankov et al., 2008). VC plays a vital role in building a vibrant private sector through the channelling of funds to young entrepreneurs unable to access seed capital from banks due to their very low appetite to finance unproven business ventures and industries (Ewing, 2004). VC investments are highly essential to EMEs due to: knowledge transfer through partnerships; high liquidity which facilitate sustained economic growth; employment generation and youth empowerment; and the identification and funding of winning firms and ideas.

VC participation has a negatively impact on the governance structure of collaborative partnership as these specialist financiers seek to gain a controlling interest in nanotech R&D projects which in turn could lead to a centralised chain of command that stifles innovative engagement among partners. Similarly, VC participation increases the possibility of short term duration and a strong value network during collaborative partnership in nanotech projects due to the specialised services provided by venture capitalists such as monitoring, industry affiliations, financial resources, etc. and their emphasis on timely divestments. Also, the likelihood of a long term collaborative partnership in nanotech R&D project depends on strong value network but reduces partnership size and vice versa. The existence of VC funding in nanotech R&D projects gives indications that there is significant commercial opportunities available and also a substantial entrepreneurial prowess prevalent in such collaborative partnerships.

H5: The higher the level of VC funding in nanotech R&D project, the greater the innovative performance of the collaborative partnership.

3.2.4.2 Financial Positioning

One of the financial resource influencers in developing innovative and profitable products by nanotech firms is the financial status…

Todeva and Knoke (2005) observe that the level of collaboration in inter-firm partnership is affected by the companies' long term objective of stakeholder wealth maximization as well as their past economic rationalities. In order words, when creating an organisational network or contractual agreement, the major factor which significantly influences the nature and extent of cooperation is the long term solvency and profitability of both companies.

H6a: The higher the solvency ratio in nanotech R&D firms, the greater the innovative performance from their collaborations.
H6b: The higher the liquidity ratio in nanotech R&D firms, the greater the innovative performance from their collaborations.
H6c: The higher the profitability ratio in nanotech R&D firms, the greater the innovative performance from their collaborations.

3.2.5 Innovative Asset Determinant of Commercially Profitable Consumer Products

3.2.5.1 Absorptive Capacity

Lane and Lubatkin (1998) define absorptive capacity as the ability of the firm to value, integrate and exploit new knowledge from external sources. The conventional measure for absorptive capacity is the R&D intensity (Lichtenthaler, 2016). Lindsay and Hopkins (2010) further argue that the use of intellectual asset strategies in preserving opportunities for or avoiding threats from disruptive innovations is critical to the survival of large corporations because of the most likely loss in their market position. According to Lindsay and Hopkins (2010), patents and other intellectual property should be used to meet the needs of low-end and prospective customers. Lindsay and Hopkins (2010) further argue that there are legitimate financial considerations for supplementing patents with publications.

H7: The higher the absorptive capacity in nanotech R&D firms, the greater the innovative performance from their collaborations.

3.2.5.2 R&D Intensity

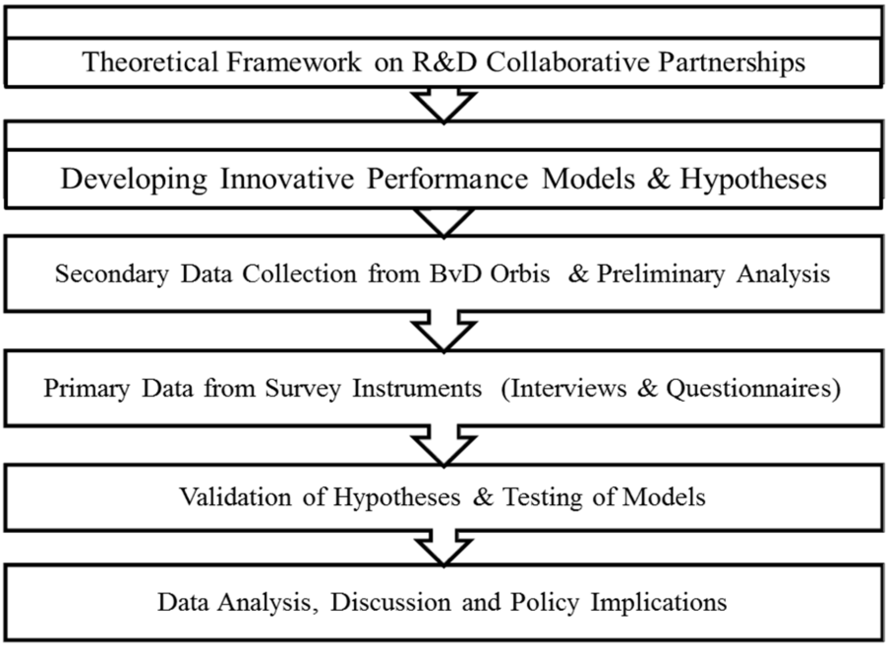
Littler et al (1995) argue that companies team up in R&D projects: to share the burden in satisfying customer needs, to explore opportunities in the market place, to counter technological changes, and reduce costs & risks associated with new product development. An innovative asset for successful collaborative partnerships in nanotech industries is vital tool for acquiring external technological know-how has been through the outsourcing of R&D activities (Grimpe and Kaiser, 2010). According to Bougrain and Haudeville (2002), R&D intensity does not severely influence the chances of a successful innovative project. The global exploitation of science and technology by MNCs better describes the much greater growth rate of international patent applications. Hoang and Rothaermel (2005) find that the collaborative experience of biotechnology partners significantly and positively influences the innovative performance of R&D projects.

H8: The higher the research intensity in nanotech R&D firms, the greater the innovative performance from their collaborations.

3.3 Research Design

I used mixed research method to systematically evaluate the internal intricacies that influence the performance of collaborative partnerships in nanotech R&D projects. *Figure 3.3* shows the research outline of this study – the conceptual framework is based on theories which provide the foundation for constructing and testing my hypotheses in order to produce empirical results on the extent to which the internal factors affect the success of inter-firm collaborations in nanotech R&D projects across Europe.

Figure 3.3: Research outline of the study



3.3.1 Data

The collaborative R&D projects in my data sample involve various characteristics of nanoscience and nanotechnologies such as the development of nanotubes and nanowires for electrical and biological consumption plus the use of nanoparticles and the construction of nanoinstruments for manufacturing and communication purposes. Specifically, these nanotech R&D projects include but not limited to: electrical discharge machining, multi-component injection moulding, electroforming, powder injection moulding, nanoimprinting, x-ray lithography, selective laser sintering, chemical vapour deposition, nanometer scale measurement and future tooling technology.

I adopted mixed research method where both quantitative as well as qualitative data were used to enrich the process of data collection and analysis. I collected secondary data on the organisational size, number of patents, VC participation and industry and academic links to nanotech R&D projects from Orbis database of Bureau van Dijk (BvD). Also, I collected from World Bank database, the annual GDP growth rates in the period of the nanotech R&D collaboration. Due to insufficient quantitative data on collaborative dynamics of nanotech firms, I used survey instruments to generate interview and questionnaire data on geographical proximity, governance mechanism, strength and duration of partnership; the responses were then coded into ordinal observations. I conducted 30 interviews with top executives of nanotech firms and provided 97 questionnaires to senior administrators of nanotech R&D projects across 12 European countries.

3.3.2 Dependent variable(s)

The key variables of interest in my study are three features of inter-firm innovative performance namely: acquiring intellectual property rights to an invention, developing a new product(s) which are commercialised and achieving profitability within five years during collaboration in nanotech R&D projects. The main dependent or response variable in my study is the number of patents secured during cooperative partnerships; the number of total patent(s) in a distinct nanotech R&D project. I also developed two other dependent variables in order to consider the other success of collaboration in nanotech R&D projects. The second dependent variable is the number of new products developed in the collaborative partnerships of nanotech R&D projects. The third response variable is the profitability of the R&D collaboration with groupings into low, medium and high levels of profit margins.

3.3.3 Independent variable(s)

While, the independent or explanatory variables varies depending on the different models used in my study and is considered to be the determinants of innovative performance for the collaborative partnerships in nanotech R&D projects based on my theoretical framework. Among the internal factors that help explain the variations in the innovation and financial performance of collaborative partnerships include: financial positioning (profitability, liquidity, and solvency ratios); human capital (dummy for previous collaboration experience, strength of the value network, the type of governance mechanism and partners size); and innovative assets (the R&D intensity ratio and a dummy for the absorptive capacity). The external factors constitute the average economic (GDP) growth rate; the geographical proximity; the legal origin index and dummies for industry affiliations (biotech and I.CT.).

3.3.4 Control variable(s)

I controlled for academic affiliations and venture capital participation in nanotech R&D organisations, using dummy variables. The number of patents held before the

R&D collaborative partnerships are also used as a proxy of determines for financial performance. This would help me better understand the effects of my independent variables on the observed variable. *Table 3.1* shows the dependent, independent and control variables in my models and their likely effects on the collaborative structure of nanotech firms.

Table 3.1: Key Variables, Expected Relationships and Brief Description

S/N	Variables	Effects	Description
1	Size of Partnership	+	The total number of partners in a collaborative R&D project.
2	Governance Mechanism	+	The type of organisational structure (coded 1-3 from centralised to distributive to decentralised).
3	Absorptive Capacity	+	Dummy variable (1) for the existence of a knowledge bank for IP & NPD in R&D project and (0) otherwise.
4	Geographical Proximity	+	The geographical nearness to industrial partners – i.e. (1-4) international, national, regional, & local closeness.
5	French Civil Law	_	Dummy variable for (1) legal origins with French Civil (0) otherwise.
6	English Common Law	+	Dummy variable for (1) legal origins with English Common law (0) otherwise.
7	Venture Capital Participation	+	Dummy variable for VC fund manager's participation in nanotech R&D projects 1 and otherwise 0.
8	Strength of Value Network	+	Level of Vertical & Horizontal Integration in nanotech R&D collaborative partnerships from survey observations.
9	New Products Developed	+	The number of new products developed due to R&D collaborations in nanotech industry.
10	Patents	+	Number of patents secured due to R&D collaborations in nanotech industry.
11	Technological Advancement	+	The country's average export demand for high-tech products in the period of R&D collaboration.
12	Academic Affiliation	+	Dummy variable, (1) for academic involvement in nanotech R&D projects and (0) for otherwise.
13	Economic Growth	+	The average rate of annual GDP growth during the period of R&D collaboration.
14	Duration of R&D Collaboration	+	Dummy variable, (1) for University-Industry R&D Collaboration and (0) for otherwise.
15	Biotechnology Industry	+	Dummy variable, (1) for nanobiotechnology type of R&D projects and (0) for otherwise.
16	I.C.T Industry	+	Dummy variable, (1) for nano-ICT type of R&D projects and (0) for otherwise.
17	R&D Intensity	+	The percentage of R&D investments divided by the nanotech firm sales revenue.
18	Solvency	+	Solvency rations from nanotech organisations involved in R&D collaborations.
19	Liquidity	+	Liquidity rations from nanotech organisations involved in R&D collaborations.
20	Profitability	+	Profit margins in nanotech organisations involved in R&D collaborations.

Sources: Orbis, Zephyr, FAME, Preqin, World Bank Open Data, IMF Data, and La Porta *et al* (1999) & Hofstede (1994) Indexes.

3.3.5 Multiple regression models (OLS)

Since collaborative partnership can be observed in several ways, I developed three regression models which are aimed at incorporating the different forms of collaboration in nanotech R&D projects. In this research study, I adopted three different performance attributes of collaborative partnerships in terms of its patents, new product development and profitability. I use multiple linear regression models to derive OLS estimates which minimize the squared residuals of best fit. I specify my initial regression models for this research study in the equation 1 below:

$$\gamma_i = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} + \cdots + \beta_k X_{k,i} + \varepsilon_i \qquad i = 1,2 \ldots n$$

Where γ is the response variable for the ith observation which is the size of collaborative partnerships in all 97 R&D projects; β0 is the constant or intercept which depicts the relationship that exists without the inputs of my explanatory variables. β1 to βk are the parameters and Ӽ1 to Ӽk are the coefficients while ε is the error term which describes the random element of the linear relationships between explanatory and response variables.

3.4 Results

In this section, the findings of the regression models are presented. Descriptive statistics and the correlation matrix are presented in *Table 3.2* and the multiple and logistic regression models are presented in *Table 3.3*.

3.4.1 Descriptive statistics

In *Table 3.2*, the mean and standard deviation depicts the measures of central tendency and dispersion of my dataset.

3.4.2 Inferential statistics

In this study, I presented three different performance attributes of collaborative partnerships in terms of its patents, new product development and profitability. In *Model 1*, I focused on the factors which determine the innovation performance of nanotech R&D organisations; using the number of total patents secured in a distinct nanotech R&D project, as a proxy for innovation performance. In *Model 2*, I focused on the determinants of new products developed in the collaborative partnerships of nanotech R&D projects; using the total number of new product developments in a distinct nanotech R&D project, as another proxy for innovation performance. And in *Model 3*, I concentrated on the influencers of the financial performance of nanotech R&D organisations; using the levels of profit margin in a distinct nanotech product or service.

Table 3.2: Descriptive statistics and correlation matrix

	Variables	Mean	Std. Dev	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Patents	2.079107	0.7563398	1																			
2	English Common Law	3.261364	0.9528459	-0.0574	1																		
3	Size of Partnership	1.875	0.7847225	0.202	0.2026	1																	
4	Absorptive Capacity	16.9696	5.903146	-0.0236	0.0421	-0.0155	1																
5	VC Participation	0.2061856	0.4066669	0.1563	-0.3195	0.063	0.252	1															
6	Strength of Value Network	0.0343229	0.1427487	0.3861	0.0082	0.1	0.0198	0.1105	1														
7	New Product Development	0.6591614	8.335254	0.1419	-0.0045	0.0104	0.1043	-0.0626	-0.2386	1													
8	Profitability	1.255989	7.886193	-0.0217	-0.0775	0.0323	0.2635	0.1082	0.6214	-0.2355	1												
9	Liquidity	0.0481982	0.241778	-0.1763	0.0702	-0.0053	0.3855	-0.0115	-0.2181	0.0191	0.0925	1											
10	Solvency	0.7438308	1.521452	-0.2878	-0.0139	-0.1326	-0.4072	-0.2871	-0.1052	0.6618	-0.1007	-0.1228	1										
11	Previous Experience	3.247423	0.8295447	-0.0784	0.0018	0.4318	0.0441	0.0255	-0.058	0.0128	-0.0947	0.1291	-0.0233	1									
12	Governance Mechanism	2.175258	0.841753	-0.0885	-0.136	0.2129	-0.0171	0.3246	-0.1179	0.2566	-0.0326	-0.2369	0.2523	0.0849	1								
13	Geographical Proximity	1.814433	0.6820603	0.0255	0.0939	-0.4166	-0.115	-0.1412	0.0683	0.0783	0.0454	-0.1376	0.1076	-0.7247	-0.246	1							
14	Duration of R&D Collaboration	3.010309	1.015452	0.1135	0.2433	0.3361	-0.0585	-0.1672	0.2	-0.1308	0.0034	0.0988	-0.1073	0.182	-0.34	-0.106	1						
15	Biotechnology Industry	0.0103093	0.1015346	-0.1746	0.1055	-0.1568	0.1725	-0.0747	-0.1772	-0.0231	-0.0466	0.0093	-0.0684	-0.0664	0.1206	0.0599	-0.053	1					
16	I.C.T Industry	0.1134021	0.3187308	0.2117	0.1212	0.0343	0.0531	-0.1733	0.0242	0.2009	-0.0464	0.2495	0.0749	0.128	-0.0808	-0.063	0.1444	-0.0407	1				
17	Academic Affiliation	0.0309278	0.1740216	-0.0493	-0.1342	-0.1013	0.1143	0.1142	-0.0996	-0.0362	0.0037	0.3052	-0.0997	0.0499	0.1721	-0.069	-0.0756	-0.025	-0.058	1			
18	Economic Growth Rate	4.1874845	8.1154894	-0.0388	-0.1426	0.2395	0.0727	-0.4836	-0.2337	0.5093	0.1933	-0.0775	0.0323	0.1135	0.1958	0.0323	0.2433	0.1082	-0.32	-0.078	1		
19	French Civil Law	2.5468987	5.15184	-0.0939	0.6226	0.0191	-0.1051	-0.3301	0.0058	-0.304	-0.6232	0.0702	-0.0053	-0.1746	0.0424	-0.005	0.1055	-0.0115	0.032	0.1212	0.0242	1	
20	Export Demand for High-Tech	29.1584	4.71239	0.2521	-0.193	-0.0081	0.0121	0.2496	0.0112	0.1481	0.0557	-0.0139	-0.1326	0.2117	0.3591	-0.133	0.1212	-0.2871	0.193	-0.134	-0.1	0.3361	1

Table 3.2 depicts the mean, standard deviation and correlation matrix

Table 3.3: Multiple Regression Coefficients for Nanotech R&D Projects

	(Model 1) Intellectual Property	**(Model 2)** New Product Development	**(Model 3)** Long-Term Profitability
English Common Law	-0.0365 (-0.65)		
Partner's Size	-0.0335 (-0.36)	1.508* (2.20)	-0.667 (-1.94)
Absorptive Capacity	-0.0812*** (-6.19)	0.870*** (10.91)	0.911*** (12.15)
VC Participation	-0.0930 (-0.63)	1.617 (1.41)	-1.729** (-3.33)
Value Network	2.792*** (6.12)	-21.86*** (-4.89)	8.402** (3.12)
NPD	0.0943*** (9.25)		-0.831*** (-9.76)
Profitability	-0.00517 (-0.65)	-0.0713 (-1.13)	
Liquidity	0.0873 (0.25)	-2.394 (-0.85)	3.032* (2.50)
Solvency	-0.575*** (-9.07)	5.838*** (18.32)	4.376*** (8.28)
R&D Intensity	0.325 (0.07)	0.243 (0.09)	0.137 (0.04)
Previous Experience	-0.246* (-2.14)	1.014 (1.15)	-0.110 (-0.26)
Govt. Mechanism	-0.0165 (-0.19)	-0.481 (-0.68)	0.425 (1.43)
Geographic Proximity	-0.266* (-2.07)	2.315* (2.21)	0.302 (0.61)
Duration	-0.0258 (-0.30)	-0.457 (-0.77)	0.285 (1.19)
Biotechnology	-0.0737 (-0.18)	0.228 (0.07)	-3.167* (-2.39)
ICT	0.242 (1.24)	0.684 (0.40)	-1.126 (-1.50)
Academia	-0.0235 (-0.08)	1.566 (0.62)	0.604 (0.60)
GDP Growth		4.420 (1.11)	
Intellectual Property		7.029*** (9.89)	4.283*** (5.59)
French Civil Law	-0.0414 (-0.78)		
Constant	5.220*** (7.23)	-39.91*** (-7.20)	-26.44*** (-7.30)
Observations	58	63	55
Adjusted R^2	0.7585	0.8929	0.9515

*The p-value is in parenthesis and the statistical significance is ***1%, **5% & 10%.*

The multiple regression results show that the innovation and financial performance of collaborative partnerships in nanotech R&D projects are significantly affected by certain internal factors namely: the absorptive capacity, strength of value network, level of solvency and liquidity, size of partnership, and previous experience in R&D collaborations. Also, nano-biotechnology alliances and the geographical proximity influence the commercial success of collaborative partnerships in nanotech R&D projects. I find that the most important internal determinants of nanotech R&D firms is its ability to recognise and acquire external knowledge for useful applications in order to successful develop nano-products which have long term profitability.

More so, I find that the strength of the value network of the collaborative partnerships in nanotech R&D projects positively influence the attainment of patents and long term profitability but negatively affects the development of new products. I also find that the larger the collaborative partnership size, the greater the development of new products. The results show that the geographical distance in nanotech R&D collaborative partnerships negatively affect the acquisition of patents but positively influence the development of new nanotech products. Successful R&D collaborations in nanotech organisations reliant on highly skilled scientists which operate on very complex instruments that require some level of proximity in order to enhance productivity within a stated period of time.

3.5 Discussion and Implications

In this section, I would identify possible opportunities and challenges for policy makers and organisational strategists to exploit or guard against; in order to enhance various dimensions of collaborative partnerships within the nanotech R&D projects.

3.5.1 Human Capital

A large number of partners in nanotech R&D collaborative partnership provide a bundle of diversification benefits which influences the creativity and productivity in R&D projects. However, large partner’s sizes in R&D collaborations only facilitate the development of new products and do not significantly affect the securing of patents or the profitability of newly developed products. It means that R&D project managers or organisational strategists must focus on unique procedures which integrates each aspect of the collaborative partnership in such a way that all parties involved are required to understand and appreciate the legal and commercial external dimensions of the R&D project so that early profitable opportunities are identified, legal barriers are mitigated, intellectual property rights are secured and future market trends are recognised and exploited.

The value network of a collaborative partnership in nanotech R&D projects is considered to be very strong when it is deeply integrated vertically and horizontally from their supply-chain in order to meaningfully enhance the innovative performance of R&D projects. However, a strong value network does not necessarily mean that new products will be developed because of the complexities in nanotechnology production. Nonetheless, R&D project managers are required to maximize human resources in a way that circumvents the challenges and riskiness of developing new products which are safe and viable in the market place. This would require having a structural procedure in place which seeks to facilitate timely interactions among all partners in such a way that the conceptualisation of new products are harmonised at inception and strategically evaluated by top managers so that adequate resources could be channelled into the development of these new products on time.

Previous experiences provide ample ammunitions to R&D project managers in the form of collaborative knowledge. Having an awareness of what to look out for and guiding against common pitfalls are some of the advantages of obtaining useful previous experiences in R&D collaboration. However, R&D project managers should be mindful of the fact that previous experience is only a guide and do not necessarily affect future R&D collaborations. This means that old organisational procedures and strategies should be moderated to accommodate new types of partners and new ways of collaboration to maximize the contributory effects on the innovative performance of nanotech R&D projects. It must be emphasized that adequate documentation of previous collaborative partnerships is imperative because of the need for constant referrals on what works or on what should be avoided.

3.5.2 Financial Positioning

A high financial position or status of nanotech firms equips R&D project managers with sufficient tangible and intangible resources to engage into complex collaborative partnerships which yield innovative performing outcomes. In order words, a highly profitable, solvent and liquid nanotech firm would be able to form large collaborative partnerships with international reach so as to coordinate useful networks which are more likely to contribute significantly to the development of new products during R&D collaborations. The presence of a financially stable nanotech firm in collaborative partnerships provides implicit guarantees and explicit endorsements that the R&D projects would likely succeed due to the availability of additional resources which could be deployed if needed. For instance, a high solvency in nanotech firms creates a huge valuable financial position which is able to ensure initial funding from long-term reserves and relative stability in R&D operations during constricting economic periods and in times of rising unexpected litigation costs.

Also, financial institutions and government agencies are willing to participate in the funding of nanotech R&D projects when the firms in collaborative partnerships have serviceable debt levels which do not bring additional economic liabilities or legal constraints. Nanotech firms with evidence of strong past financial performance in terms of profitability and liquidity are placed on a higher status during negotiations as weaker or smaller new partners are happy to make some concessions in other to be part of an exclusive R&D project which has a good chance of success. In general, some financial performance indicators could provide a significant insight on factors that influence the innovative performance of R&D projects. The presence of VC funding in collaborative nanotech R&D projects means that a much specialised financial expert would provide useful counsel on the most commercially viable path to pursue in the quest to create an innovative product which meets profitable consumer needs because of the active participation and strong influence VC fund managers usually obtain through contractual obligations.

3.5.3 Innovative Assets

Innovative assets are considered as a main determinant of innovative performance in R&D projects (He and Wang, 2009). The ability of a nanotech firm to retain previous knowledge and integrate it into their current operating system means that new external knowledge would likely be efficiently managed to stimulate innovative outcomes because the best industry practice and successful previous processes would be adopted effectively to take advantage of key business opportunities which enhance the innovative performance of nanotech R&D projects. A critical issue here could be developing a governance mechanism which provides nanotech R&D project managers with a reasonable level of discretion in making key resource reallocation decisions and gives their financial sponsors adequate monitoring tools to reduce information asymmetry.

3.5.4 Industry and Academic Affiliations

Also, industrial affiliation could provide commercial opportunities for innovative nanotech R&D projects due to the conglomeration of specialist high-tech firms in different pioneering sectors. I argue that the absence of institutional diversity impedes on the overall ability of the collaborative partnership to maintain a steadfast development of new and innovative products or secure exclusive rights to an intellectual property. Biotechnology organisations are usually bombarded with stricter regulatory requirements which increase the complexities in collaborative partnerships for nanotech R&D projects and usually lead to delays in securing patents or developing a new product. Whereas, academic affiliations in whichever field can simplify nanotech R&D projects due to emphasise on open sources and established methodologies which are easily verifiable by regulatory authorities.

3.5.5 Legal Origins

Nanotechnology is an emerging technology that has few laws which regulate its industry. The French and German legal systems provide a greater level of flexibility for securing patents and higher scale of predictability for estimating litigation outcomes; which makes it appealing to more nanotech R&D collaborative partnerships because there is little regulation restricting the nature and scale of research exploration and commercial exploitation or which could pose a huge threat and possibility of large losses, as opposed to the English common legal system, where there is an inherent rule to have minimum standard of care. The negative effects of nanotechnology highlight the need for a thorough risk assessment to be carried out along with the pace of vast commercial developments. It is imperative for nanotech firms in common law countries to take into consideration the additional cost required to make available to the public risk assessments about the possible effects of their R&D projects in order to enhance public awareness and reduce the general tolerance for uncertainties associated with nanotechnology.

3.5.6 *Proximity*

Despite the advancements in information and communication technologies (ICT) as well as the free movement of capital and labour across Europe, the geographical distance still matters greatly in determining the innovative performance of collaborative partnerships in nanotech R&D projects. The spatial nearness among scientists negatively influences the securing of intellectual property rights but positively affects the development of new products and service in nanotech R&D projects (Knoben and Oerlemans, (2006). Nanotechnology as an interdisciplinary field which requires a great deal of physical closeness among R&D partners using very complex instruments to develop innovative products and services through a decentralised system of governance which minimizes contingency risks (Steinmo and Rasmussen, 2016).

The lack of a concentration of nanotechnology experts within a local scientific community in the past has created a situation where there is the need for international collaborations with a distributive organisational structure; in spite of the drawbacks from their geographical distance (Kabo et al., 2014). However, proximity that relates to the nearness of partners in terms of their operations and area of specialty during the R&D collaborations should be the focus of management. The quality of the value network are strengthened when there were substantial division of labour and clearly defined roles which enable partners uniquely contribute into the nanotech R&D project; within a strategic time frame that seeks to attain specified commercial objectives. A strong value network and a long-term R&D collaboration among nanotech firms are more likely to be negatively affected if there are high levels of functional closeness within the partnership.

3.5.7 Cultural dimensions

Cultural value do not easily change in the short run and is usually passed from one generation to another; making it expedient for policy makers and corporate strategists interested in nanotech R&D collaborations to understand the possible implications and predictable behaviours relating to risk tolerance, procedural controls, and adherence to norms within a community that they operate in, so as to promote discussions that alleviate unproven claims, improve negotiating processes, and reduce litigation costs (Hong, Heikkinen, and Blomqvist, 2010). The level of tolerance for uncertainty within a nation reveals her cultural attitude towards risks and ambiguity (Sriwindono and Yahya, 2012). Countries which have high uncertainty avoidance indicators are more likely to have a rigid belief system that could be intolerant of unorthodox and risky behaviours due to the fact that the majority of people with such cultural values are sensitive to, and feel uncomfortable with unstructured or changeable environments.

However, countries with low uncertainty avoidance indexes evince that members of a society are more likely to be forbearing towards ambiguous or uncertain R&D ventures because they are entrepreneurial in nature and are likely to feel comfortable in risky and less structured environments. In these countries, nanotech R&D project managers can take advantage of the politically active and very informed population, by making quick decisions which exploit innovative concepts. A high proportion of female involvement in science and technology within a country would more likely increase the strength of value networks and reduce the time period of collaborative partnerships in nanotech R&D projects. Whereas a more dominant male presence usually leads to ego oriented inter-firm relationships which promote fierce competitions and focus on profit maximization, irrespective of the impact on the external environment.

3.5.8 Economic growth

Periods of economic growth positively affects the innovative performance of collaborative partnerships in nanotech R&D projects as a result of the availability of several funding prospects, the prevalence of commercial opportunities and the rise in labour participation. In knowledge-based economies, the expansion of economic activities usually leads to a rise in R&D expenditures. Most universities normally obtain huge funds from research councils and industry partners to finance their R&D projects with the aim of building innovation centres and fostering regional economic development (Bilbao-Osorio and Rodriguez-Pose, 2004; Guerrero, Cunningham, and Urbano, 2015).

University-Industry collaborative partnership is a key ingredient that stimulates productivity in innovative ventures (Jong and Slavova, 2014) and accelerates the growth of economic activities in advanced countries. An increase in the external R&D activities of high tech firms has resulted in the rapid rise of inter-organisational relationships which lead to patent licensing agreements and the development and production of new products. The commercialization of R&D activities via university-industry collaborative partnerships has brought not only economic development but also the technological advancement of nations due to the international demand for their high-tech products which is usually an emerging or disruptive know-how. Having exclusive rights to an innovative product in the form of a patent provides nanotech firms with the required protection for their intellectual property and encourages more R&D projects in the future.

3.5.9 Technological advancement

As a result of globalisation, many countries have been able to unlocked localised industries by taking advantage of new and existing export opportunities for high-tech products and services around the world (Mehta, et al. 2012). Most barriers and challenges in international commerce have been alleviated by world trade organisation as advanced nations and large corporations are able to attract high skilled labour and sophisticated investments into emerging and disruptive industries to provide technologically advanced products and services for worldwide consumption. The export demand for high-tech products evinces the level of technological advancement in a country. Most MNCs have their internal R&D capabilities at their headquarters and many external R&D projects are organised in their home country. Nanotech firms that operate in technological advanced nations are more likely to sell their newly developed innovative product to international markets; and also more likely to have a shorter time period in collaboration due to their centralised governance mechanisms and comprehensive value networks.

3.6 Conclusion

Collaboration in high-tech R&D projects usually involves huge funds and expertise which divert strategic resources away from internal R&D investments. However, most large high-tech firms deliberately seek to capitalise on economic opportunities from their existing portfolio of intellectual properties in order to take advantageous position in negotiations and strengthen their bargaining chips for cross-licensing other patented technologies. The bundle of diversification benefits which a large number of partners provide in a high-tech collaborative partnership influences the scientific productivity and innovative performance in nanotech R&D projects. For instance, the existence of a financially stable and profitable high-tech firm in collaborative partnerships provides implicit guarantees and explicit endorsements that such R&D projects would likely succeed due to its accessibility to additional resources which could be deployed to ensure support and provide some valuable liquidity for R&D operations during periods of economic decline and unexpected litigation costs.

Also, large high-tech firms usually employ intellectual properties as a strategic instrument to stifle competition. Globalisation has helped many countries to unlock localised industries by taking advantage of new and existing export opportunities for high-tech products across the globe. Advanced nations and large corporations are able to attract high quality human capital and sophisticated investments into emerging and disruptive industries to provide technologically advanced products and services for worldwide consumption. The value network of a collaborative partnership in nanotech R&D projects is strong when it is intensely incorporated vertically and horizontally from their supply-chain in order to meaningfully enhance the innovative performance of R&D projects. However, a strong value network does not necessarily mean that new products will be developed because of the complexities in nanotechnology production. Institutionalizing collaborative partnerships are extremely challenging because R&D projects demands new organisational structure and procedure which harness available resources to achieve set objectives.

As a discontinuous innovation-based technology, nanotechnology has few laws which regulate its industry, requires highly skilled scientists from different disciplines to work in close proximity and operate on very complex instruments in order to create innovative new products within a specified period of time. Nanotechnology as an interdisciplinary field which requires a great deal of physical closeness among R&D partners despite the advancements in ICT as well as the free movement of capital and labour across Europe. Legal systems which provide a greater level of flexibility for securing patents and higher scale of predictability for estimating litigation outcomes; are likely to be more appealing to nanotech R&D project managers because there is little regulation restricting the nature and scale of research exploration and commercial exploitation or which could pose a huge threat and possibility of large losses.

Universities that involve in discontinuous innovation-based R&D projects have specialised interdisciplinary centres which are capable of collaborating with more industrial partners because of their reliance on additional financing to. Patents and other intellectual property should be used to meet the needs of low-end and prospective customers. In addition, academic institutions are now benefiting from the legitimate financial considerations of supplementing patents with publications. The existence of VC funding in nanotech R&D projects gives indications that there is significant commercial opportunities available and also a substantial entrepreneurial prowess prevalent in such collaborative partnerships. There are other significant variables not included in this model which still influences the ability of nanotech companies to collaborate with large number of industrial partners. Certain key features of a company such as its age, size, market position, and financial status, could be useful tools in predicting the propensity to enter successful collaborative partnerships. A much larger sample size which incorporates more countries that nanotech companies operate in would provide useful insights into legal and cultural determinants of the innovative performance of collaborative partnerships.

Chapter 4: Innovative and Financial Firm Performance of Nanotechnology R&D Organisations in the Commercialisation Era

4.1 INTRODUCTION

The beginnings of nanotechnology could be traced to the now famous lecture delivered by Scientist Richard Feynman on the 29^{th} of December 1959 at the American Physics Society's meeting in California Institute of Technology. It was a visionary discourse which was titled 'there's plenty room at the bottom' and envisaged the possibility of developing minuscule machines which could 'arrange the atoms the way we want' and perform chemical synthesis through mechanically manipulating matter on an atomic scale. In 1974, Japanese Professor Norio Taniguchi coined the term 'nano-technology' at the Tokyo Science University, when he tried to describe the accurate creation of materials with the tolerances of nanometer. The profound breakthrough in the study of nanoscience and nanotechnology came when few researchers at one of IBM's global research laboratories in Zurich, Gerd Binnig and Heinrich Rohrer in 1981 invented the scanning tunneling microscope (STM) which used specimens that conduct electric current only; and then Binnig and some other scientists in 1982 created a more versatile nano-instrument called the Atomic Force Microscope (AFM).

Among scientists, there is a strong consensus that these two inventions brought about the accelerated march into the modern nanoworld with the enhanced ability to image and manipulate molecules at the nanoscale. Consequently, IBM Corporation is considered as one of the foremost organisation responsible for catapulting the study of nanotechnology to the forefront of physical science research due to the fact that its multinational Research Center in Europe developed the innovative scanning probe techniques (STM and AFM) which became prevalent in the field of instrumental analysis because of the volume of nano-meter-scale information these new scanning methods provide and this earned the scientists in 1986, the Nobel Laureate Awards in Physics. In the same year, Eric Drexler published the 'Engines of Creation: The coming Era of Nanotechnology' which became the basis of his MIT doctoral thesis in 1991. Researchers became equipped with the ability to evaluate structures measuring just a few billionths of an inch, as scientists Donald Eigler and

Erhard Schweizer in 1991 at IBM's Research Center in the US made it known that they have been able to draw letters on a cold nickel crystal by prudently arranging a handful of xenon atoms in sequence.

Most policymakers and top scientists highlighted the numerous benefits that accrue to the economy and the entire society. The key role that R&D policies would play became even more obvious, over the years and across the globe, in the value-creation process of judiciously exploring and economically exploiting portfolios of nanotechnology products and services which are deeply entrenched in my everyday life. In the late-1990s, after almost two decades of incessant scientific productivity in the field of nanotechnology, most liberal democracies and emerging market economies where seeking to enhance the domestic prospect and international position of this key high-tech industry so as to gain competitive technological advantage in an ever-increasing globalised socio-economic environment. President Clinton in 1997 said that we have to "Imagine a new century, full of promise, moulded by science, shaped by technology, powered by knowledge. We are now embarking on our most daring explorations, unravelling the mysteries of our inner world and charting new routes to the conquest of disease".

As an engine for economic growth, job creation and radical innovation in knowledge-based economies (Protogerou et al., 2017); high-tech firms play an important role in establishing collaborative partnerships with universities (Caloghirou et al., 2001); securing government and private R&D investments (Roco, 2011); in order to develop a portfolio of innovative products and pioneering systems (Nieto and Santamaria, 2007) which thrives despite the swift changes in the socio-economic and technological environments (Baranenko, et al., 2014) that requires shorter product life cycles as a result of intense global competition (Deeds, DeCarolis and Coombs, 2000). Through R&D initiatives, government has vigorously financed inter-firm R&D projects (Roediger-Schluga and Barber, 2006; Paier and Scherngell, 2011) to promote innovative performance in high-tech firms so as to enhance their global competitiveness (Scherngell and Lata, 2013).

Globalization of science, technology and commerce has rapidly advanced human endeavour; making it essential for high-tech firms to continually improve their product lines and manufacturing processes to meet the ever-increasing stakeholder expectations (Lo et al., 2011). Consequently, the internationalization of economic activities and consumer preferences cause high-tech firms to become more strategic in pooling both internal and external R&D resources together through offshore outsourcing (Bertrand and Mol, 2013) or local collaborative networks (Bresciani and Ferraris, 2014); with the objective of producing multi-technological goods which attract huge export demand from international markets (Narula, 2004). In the early 2000s, nanotechnology rapidly took a strategically important role among most governments in advanced countries as a result of the recognition of its tremendous economic potential. Certain key R&D policies were initiated to quickly facilitate the commercialisation of nano-products and the convergence of nanotechnology with other technologies. Emerging economies like China and Russia have enthusiastically jumped into the bandwagon which has spurred the globalisation of nanotechnology advancement. Some management research have looked into the classification of the historical developments and future trends based on scientific publications and patent applications usually employing textual mining techniques to observe useful information from global open sources such as SCI/SSCI databases (Kostoff, et al. 2006, 2007).

There is the absence of a thorough empirical investigation which analyses the performance of nanotechnology firms and forecast the future trends for profitability of nano-products. In my study, I evaluated the key factors that influence the innovative and financial performance of nanotechnology firms from an investor’s perspective and I discuss the effects of national nanotechnology initiatives on the scientific productivity and innovative, especially at the turn of the 21st century, when various government initiatives was undertaken to expedite the commercialisation of molecular engineering. The comprehensive investigation of the antecedents for a successful R&D strategy in the commercialisation of nanotechnology firms has been documented (Fiedler and Welpe, 2010); however, in this research report I would endeavour to categorise the internal and external determinants of the performance of nanotechnology firms.

Previous organisational studies have shown that knowledge creation and the assimilation of information through universities is significant for industrial innovation, as high-tech firms are well-known to develop and accumulate vital technological capabilities based on formal and informal modes of organisational learning

(Belderbos, Carree and Lokshin, 2004; Czarnitzki, Ebersberger and Fier, 2007; Maietta, 2015; Thoma, 2017). The increasingly complex, extremely expensive and highly interdisciplinary features of modern scientific activities have resulted in the rise of inter-organisational R&D partnerships (Teece, 1986); as a cost effective means for high-tech firms to access and exchange new knowledge, secure additional human capital, develop innovative methods, improve value network and enter into heavily regulated markets (Matt, Robin and Wolff, 2012); in order to benefit from the diversification of risks, transfer of scientific knowledge, enhanced market competitiveness, greater return on investment, better rate of survival, improved reputational status and brand recognition.

The motivation of this study was dependent on my inquisitiveness in understanding the extent to which factors under management control influences the different types of innovative performance in nanotech R&D firms across the globe so as to provide corporate strategists with valuable information on the internal intricacies which expedite creativity, productivity and profitability in nanotech firms. My study evaluates the main internal determinants of the amount of patents, quality of new product development and level of profitability of nanotech R&D organisations across the globe. I looked intensely at the human capital, financial resources and inventive assets of nanotech firms; while controlling for their previous cooperative experience, duration of collaboration and VC participation. The main research question for my study is how do internal and external factors affect the innovative and financial performance of nanotech R&D firms across the globe? My research objective is to provide nanotech managers of R&D projects with valuable knowledge on how the structural internal and external dynamics of nanotech firms affects the attainment of significant patents, new product development and profitability.

The key contribution of this research study is to provide policymakers and corporate strategists with useful insights into the internal and external environment of nanotech firms. The major factors that influence the performance of nanotechnology institutions across the globe are the country's legal origins, cultural dimensions, rates of economic growth, export demand for technologically advanced products of high-tech firms controlling for their organizational size, VC participation, and research intensity. I employed multiple regression and panel data analysis to evaluate the relationship between successful nanotech R&D firms and key performance indicator variables. I then conclude by ascertaining the core internal dynamics which corporate strategists and R&D project managers need to be aware of, as the onus is on top managers of high-tech organisations is to design simpler and flexible governance mechanisms which builds the firm's capacity to retain and integrate new knowledge and innovative techniques into existing corporate systems during periods of high financial positioning with the intention of maximizing technological productivity and commercial performance.

I collected secondary data on nanotechnology organizations and their industry affiliations, organizational size (total assets), number of patents, and VC participation from the Orbis database provided by Bureau van Dijk (BvD). The results show that external factors – such as a country's legal origin, cultural dimensions, economic growth and its export demand for advanced high-tech products – meaningfully influence the size and governance mechanism, strength and duration of collaboration in nanotech R&D projects. The closeness, regarding geography and functional space, of nanotech R&D firms most influences the dimensions of their R&D collaborations. Also, nanotech firms operating in countries with French Civil Law origin are inclined to establish a centralized system of governance in their R&D collaborative partnerships, due to the high level of legal predictability. Countries with a legal origin in English Common Law are less predictable, while those with French Civil Law are less flexible (Beck et al., 2003). I also find that VC funding in nanotech R&D firms usually leads to VC's active participation in the strategic management in order to influence their innovative and financial performance.

Moreover, my results show that the innovative capacity and organizational size of nanotech firms also affect the dimensions of their R&D collaborations (Fiedler and Welpe (2010). I argue that, because nanotech R&D projects are inherently very complex, nanotech firms that operate with a more decentralized internal organizational structure and in a simpler external environmental framework will be more effective in their R&D collaborations and hence can produce better innovative outcomes for a more abundant world. My study concludes by identifying the possible opportunities and challenges for policy makers and organizational strategists to exploit or guard against, to enhance the dimensions of collaboration within the nanotechnology industry or similar emerging and discontinuous innovations. The research study is structured as follows: In section 4.2 I introduce the theoretical framework of the study and develop the hypothesis. Section 4.3 outlines the research methodology. The empirical results are presented in section 4.4. The section 4.5 discusses these results and highlights research and policy implications.

4.2 LITERATURE REVIEW

Nanotechnology is a scientific phenomenon that is creating an international gold rush from its transformative technological usefulness in revolutionising the energy, defence, IT & Communications, healthcare, agriculture and the environmental sectors (Jiao et al., 2016). As an enabling innovative system, it relies on the continuous development of its basic science but also the exploitation of different commercial attractions in its industrial application. However, the challenge is to derive an optimal R&D strategy which doesn't sacrifice genuine scientific breakthroughs for exorbitant financial payoffs (Rao et al., 2013). The review of the extant literature of my study and develop hypotheses for testing. I observe how the theoretical framework, scientific discoveries and commercial applications of nanosciences and nanotechnologies evolved to become one of the new frontiers of science and technology around the world.

4.2.1 Historical Developments in Basic and Applied Nanotechnology Research

Kostoff et al., (2006b) defines nanotechnology as the development and application of techniques. Shea (2005) suggests that nanotechnology is a multipurpose application of science that has radical innovations in processes, disruptive impact on existing industries and transformative effect in societies. Kostoff et al., (2006) using visual inspection of the historical records of seminal papers categorize research studies in nanotechnology into solid state electronic structure; optics/spectroscopy; surfaces/films/layers; instrumentation and materials. The extant literature in nanotechnology consists of two main periods of intellectual heritage: pre- and post-1985. From the early decades of the 20th century, nanotechnology research studies have focused on the development and application of techniques to examine physical phenomena. Mie (1908) proposes the conventional electrodynamic study of the extinction cross-section which was the early development of optical extermination of light by an insulated circular element to size and rate of recurrence.

Fowler and Nordheim (1928) develop a model to explain the electron emission from metals for current densities and tunneling currents. Also, models like the effective medium where developed by Bruggeman (1935) to solve the inhomogeneous media so that the various stages are randomly dispersed in terms of particles of an arbitrary size, shape, and orientation. One of the post-world war 2 advances in nanoscience was the appropriate interpretation of X-ray diffractometry to study microstructures. Stoner and Wohlfarth (1948) design a model that could depict the magnetization reversal of a single-domain nanoparticle. In 1964, Rotenberg and Kohn postulated the density-functional theory used in explaining the ground state of predetermined electron structures. Meanwhile, Rietveld (1969) develops a technique for profile refinement of nuclear and magnetic systems which directly incorporated the profile forces derived from step-scanning metrics of neutron powder structure. Shannon (1976) ascertains the effective ionic radii which produces a useful platform for calculating crystal structures. Ceperley and Alder (1980) employ the critical addition of the quantum many-body algorithm to electronic system assessments which uses a random technique to calculate ground-state of the electronic gas. Sze and Churchill (1981) propose the fundamental dynamics and operational features of all key bipolar, unipolar, special microwave, and optoelectronic procedures. However, since the transition from nanoscience to modern nanotechnology in the mid-1980s due to the commercial availability of and technical advancements in instruments that allow for adequate scanning and probing at the nanoscale level; construction of structures in the nanoscale size range has been the focus of and trend in nanotechnology research.

The development of the Scanning Tunneling Microscope (STM) in 1981 and Atomic Force Microscope (AFM) in 1986 from about the ability to carry out current nanotechnology research demands the advancement of many technical disciplines (Kostoff et al., 2006). Katz and Martin (1997) define research collaboration as the meaningful cooperation of researchers in achieving a collective goal of creating and disseminating new scientific knowledge. Katz and Martin (1997) observe that collaboration could be developed among individual researchers such as interdisciplinary groups; across public/private sectors such as university and industry; and between countries such as multi-national cooperation. Katz and Martin (1997) argue that the motivations for research collaborations are the rising costs of conducting experimental science; the availability of quick and avoidable transportation/communication facilities; the proliferation of scientific communities around the globe; the politicizing of research activities; and the strong demand for specialisation within the fields of science. Ponds et al (2007) observes that one of the main reasons for the surge in scientific research collaborations is due to the growth in interdisciplinary research institutes which rely on the combination of the expertise of researchers from different fields of study.

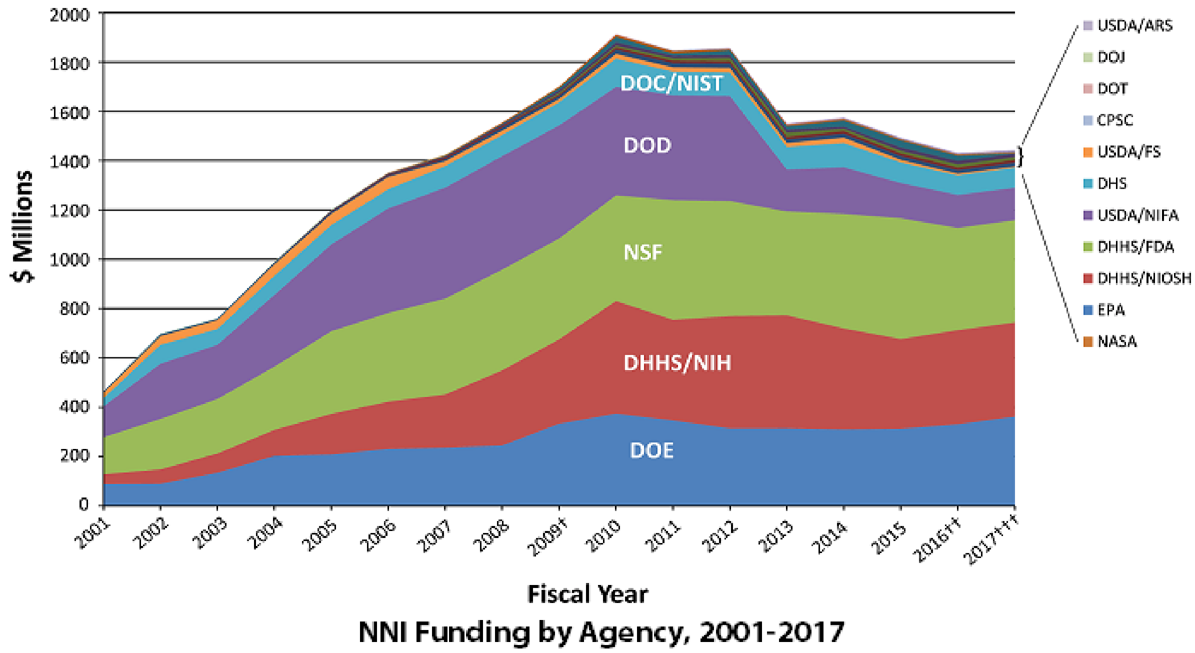
4.*2.2 Commercialisation of Nanotechnology Industries in Advanced and Emerging Economies at the turn of the 21st Century*

Nanotechnology is considered to be the first main international initiative of the 21st century because it serves as a platform for technological solutions across industries and a junction for convergence with other enabling technologies. It provides the common groundwork for and unique enablement of new innovations relevant to several industries and the societies at large (Mangematin and Walsh, 2012). Knowledge commercialisation became prominent in the 1980s and is a process where value is created from knowledge through the practical application and market introduction of R&D outcomes (Taheri and Geenhuizen, 2016). Government approaches to facilitating successful national innovation systems lies between market-driven policies and state-control mechanisms which facilitates strategic coordination for constant exchange of information between industry and academia (Rao et al., 2013).

At the turn of the 21st Century, some government R&D policies in developed countries pursued the commercialization and industrial regulation of nanotechnology products and services for lucrative but safe public consumption, after a twenty year period of intensive basic research and applied laboratory experimentations. The need for an effective government R&D strategy was astutely echoed by the then leader of the free world - US President Bill Clinton, in a speech he gave on the 21st January 2000 at the California Institute of Technology which stated that “Some of my research goals may take twenty or more years to achieve, but that is precisely why there is an important role for the federal government”. Specifically, in 2003, the United States played an important role when President George W. Bush enacted the

Nanotechnology Research and Development Act[2] which led to a $3.63 billion initial budget funding that was authorised for capital expenditure between five government agencies to finance the National Nanotechnology Initiative (NNI) aimed at: facilitating global collaborative partnerships in nanotechnology R&D projects; enhancing the structural transfer and legal exchange of newly innovative technologies among nanotechnology R&D organisations for scientific productivity and commercial developments; creating interdisciplinary scientific groups and multipurpose nanotechnology research centres for developing highly skilled scientific workforce and new educational resources; and the provision of adequate infrastructures and monitoring tools which advance nanotechnology industrialisation and promote responsible and sustainable development across a myriad of industries such as healthcare, information & communication systems, agriculture, defence, energy, and the environment for public benefit in the not too distant future.

Figure 4.1: Funding from the National Nanotechnology Initiative (NNI)



† 2009 figures do not include American Recovery and Reinvestment Act funds for DOE ($293 million), NSF ($101 million), NIH ($73 million), and NIST ($43 million)

†† 2016 estimated funding is based on 2016 enacted levels and may shift as operating plans are finalized.

††† 2017 Budget.

Source: https://www.nano.gov/node/1128

[2] *Mihail Roco first proposed the initiative in 1999, while President Bill Clinton in 2000, advocated for a twenty year holistic strategy to the development of nanotechnology in the United States and later in the year created the National Nanotechnology Initiative.*

It should be stated that at the end of the fiscal year of 2016, the cumulative NNI investments made by the United States government was almost $21 billion and that NNI now functions as the principal hub which brings together expertise from all US federal agencies that are capable of effectively advancing very complex nanotechnology research with different modes of communication, cooperation, and collaboration. The US government invested over $20 billion in nanotechnology from 2001 – 2015 (Jiao et al., 2016).

Similarly, the first major European Strategy for Nanotechnology was devised in 2004 by the European Commission (EC) which funded almost 200 EU nanotech R&D projects under the Framework Programme (FP6 & FP7) in different clusters formations which then were used to describe and explain the various scientific productivities and technological innovations within the nanotechnology industry and around the environment. As the general public was typically sceptical about nanotech projects, it was especially important for EU R&D policy makers to select and structure relevant information and use appropriate methodologies to reach target audiences in order to communicate meaningfully nanotechnology research to all stakeholders and foster societal discussion as part of essential R&D policy initiatives. Consequently, EU citizens were able to understand why nanotechnology is one of the core frontiers of scientific development today and how it is deeply embedded into our daily lives and affects us all.

As from 2005 the European Commission has supported nanotechnology R&D collaborations through her Joint Research Centres predominantly to facilitate R&D partnerships which leads to the rapid development of scientific productivity and innovative performance in order to enhance the competitive advantage for the region. There are two differing approaches applied by the policy makers in the US and EU. The US initiatives favoured a purely market driven approach towards the development of nanotechnology through the provision of adequate basic R&D resources and ensuring strict to adherence to minimum safety guidelines. While the other hand, the EU has favoured a careful government intervention in setting the agenda for the development of nanotechnology by adopting a demand-driven approach which significantly considers the safety of society and environment. This has cumulated into the protection of intellectual properties and industry oversight of nanotechnology products for consumer use and constituted the essence of the centralised R&D initiatives in EU countries.

The European Commission actively invests into joint R&D projects, in conjunction with the private sector, to facilitate inter-firm collaboration and scientific performance in an attempt to foster global competitiveness (Paier and Scherngell, 2011). A key challenge for European R&D policy makers is to define an optimal collaboration scale for fund mobilization across local, regional, national and international cooperative partnerships to promote a vibrant and prosperous socio-economic environment.

Likewise, the British government also recognised that nanotechnologies could revolutionise communities as its developments could render existing modus operandi obsolete due to some disruptive modifications to the structure of materials in production; drastic advancement in drug discovery, sensible reduction in the use of energy, efficient techniques in recycling used substances and enhanced miniaturisation in semiconductor assembly. With the aim of propagating information on nanotechnology around the UK, the National Initiative on Nanotechnology (NION) was launched in 1986 by the National Physical Laboratory (NPL) and the Department of Trade and Industry (DTI).

The LINK Nanotechnology Programme (LNP) was subsequently launched in 1988 for an eight year period; with the Science and Engineering Research Council (SERC) joining in 1989; followed by the Defence Research Agency (DRA) in 1990. The main recommendation from the Nanotechnology Theme Day in 1999 was a committed and focused R&D programme that aid interdisciplinary collaborations. In 2002, Prime Minister Tony Blair in a speech to the Royal Society was quick to single out nanotechnology as a vital field of research and states that “Visionaries in this field talk about machines the size of a cell that might, for example, identify and destroy all the cancerous cells in a body.

Nanomachines might target bacteria and other parasites, dealing with tuberculosis, malaria and antibiotic-resistant bacteria”. The labour government in 2003 commissioned the Royal Society and the Royal Academy of Engineering to analyse whether there was a need for greater oversight after Prince Charles lobbied some scientists to ‘look into grey goo nightmare’ in order to generate wider attention. The

House of Commons then suggested to the Treasury the necessity for greater investments into nanotechnology research were needed in order to sufficiently position the UK as the top destination for R&D activities. The Engineering and Physical Sciences Research Council (EPSRC) since 1997 made an annual R&D expenditure of £40 million and disburses about 10% of its total £1billion grants to research in nanotechnology. Through managed programmes and interdisciplinary research collaborations such as the National Initiative in Nanotechnology, EPSRC has promoted useful integrating initiatives which create a mixture of instruments and systems that enhance the precision manipulation of matter a molecular level in the UK.

Consequently, the Japanese government has supported the advancement of nanotechnology particularly since the year 2001 with the second Science and Technology Basic Plan (STBP) which prioritised this field as one of the national issues of interest. The funding from the government has increased over the years and targeted semiconductor technology, clean energy and life sciences innovations. Also, the private sector has invested into the development of nanotechnology for commercial purposes, as it is considered to be a key field which could revitalize industries. The Japanese government set their nanotechnology policies at the cabinet level by the Council for Science and Technology with main strategies to solve problems that relates to society and industry as well as ensure market competitiveness by promoting social acceptance, accurate measurement, effective commercial policies, and providing R&D infrastructures. About $260 million per annum is budgeted and channelled through key sectors such as Energy, Trade, Industry, Education, Health and Science & Technology. The second Science and Technology Basic Plan from 2001 – 2005 was the crucial initiative that prioritised areas of funding and facilitated interdisciplinary, inter-firm and international collaborative partnership among nanotechnology experts and organisations.

Governments in developing nations have the opportunity to leapfrog into an advanced innovative system by navigating away from the missteps of early innovators developed nations by using taxation, regulation, infrastructure development and public venture capital (Appelbaum et al., 2016). The Chinese communist government has increased funding and improved R&D infrastructure in order to significantly advance nanotechnology publications, commerce and industrialisation. One of the key basic research field supported by the Chinese government's Medium and Long-Term Development Plan was nanotechnology (Jiao et al., 2016). Developing countries have been creating national systems of innovation in R&D intensive field like nanotechnology in order to transition their economies away from low value creating industries. Preferential treatments have been given to their local high-tech companies as large funds are devoted to developing basic and applied research, building research centres, recruiting renowned scientists and even financing entrepreneurial high-tech ventures (Appelbaum et al., 2016).

Table 4.1: Modern Periods of Nanotechnology Development

	2001–2010	2011–2020
Measurements	Indirect, using time and volume averaging approaches	Direct, with atomic precision in the biological or engineering domains, and femtosecond resolution
Phenomena	Discovery of individual nanostructures	Complex simultaneous phenomena; nanoscale integration
New R&D paradigms	Multidisciplinary discovery from the nanoscale	Focus on new performance; new domains of application; an increased focus on innovation
Synthesis and manufacturing processes	Empirical/semi-empirical; dominant: top-down miniaturization; nanoscale components; polymers and hard materials	Science-based design; increasing molecular bottom-up assembly; nanoscale systems; increasingly bio-based processes
Products	Improved existing products by using nanocomponents	Revolutionary new products enabled by creation of new systems; increasing bio-medical focus
Technology	From fragmented domains to cross-sector clusters	Toward emerging and converging technologies
Nanoscience & engineering penetration into new technologies	Advanced materials, electronics, chemicals, and pharmaceuticals	Increasing to: nanobiotechnology, energy resources, water resources, food and agriculture, forestry, simulation-based design methods; cognitive technologies
Education	From micro- to nanoscale based	Reversing the pyramid of learning by earlier learning of general nanotechnology concepts (Roco, 2003b)
Societal impact	Ethical and EHS issues	Mass application; expanding sustainability, productivity, and health; socio-economic effects

Governance	Establish new methods; science-centric ecosystem	User-centric ecosystem; increasingly participatory; techno-socio-economic approach
International	Form al S&T community; establish nomenclature, patent, and standards organizations	Global implications for economy, balance of forces, environment, sustainability

Source: Roco (2011).

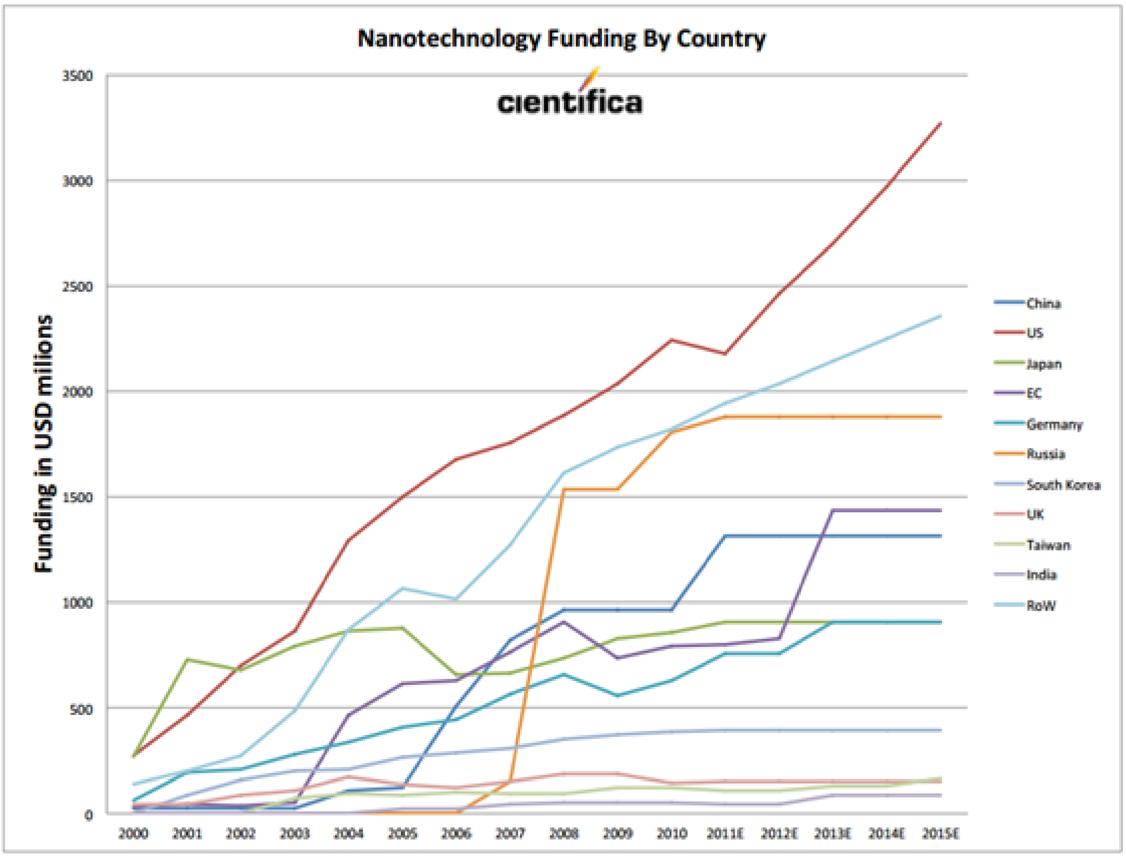
4.2.3 Public and Private R&D Funding in Nanotechnology Innovations

Nanotechnology is believed to play a central role in the future technological development and economic transformation. Hence why government policies have tried to aid and promote the commercialisation of nanotechnology by providing R&D funds, building world-class infrastructure and encouraging global scientific alliances (Rao et al., 2013). Despite the huge public R&D investments and adequate intellectual property rights protection in European countries, there has been an unsuccessful conversion of scientific breakthroughs and technological achievements into financial performing high-tech industries. Commercialisation of R&D activities in nanotechnology requires large funds, extraordinary care towards public safety, and adequate exchange of information between managers, researchers and policy makers (Rao et al., 2013).

It is paramount for the nanotechnology industry to continuously receive government funds since SMEs lack research resources and instrumentation for its early-stage development; and large companies have low financial motivation for its long-term resource commitments (Palmberg, 2008). Private companies are yet to fully participate in the commercial application of nanotechnology, while universities and government laboratories continue to dominate in the productivity of scientific outcomes (Miyazaki and Islam, 2007). One of the conditions required to attract long term foreign in high-risk R&D investments into a country's innovative system is a predictable sets of policies and objectives proceeding from government agencies with emphasis on technological breakthroughs specialised fields such as 'targeted drug delivery, ultra-light carbon-based materials, greatly enhanced water filtration, highly efficient low-cost energy production, and high-speed computing' (Appelbaum et al, 2016).

Nanotechnology is in an embryonic stage that requires long-term exploratory R&D investments from governmental agencies in different key sectors to stimulate its successful commercialisation which is estimated to be worth $1 Trillion by 2020 and spark the second industrial revolution (Lo et al., 2012). Governments in developing countries heavily depend on luring expatriate scientists and acquisition of foreign technology. Weaning themselves of such dependence usually leads to the construction of industrial policies which focuses public R&D investments into key areas of basic science, applied engineering and industrial technology for the purpose of driving new product innovation among domestic high-tech companies in order to foster economic growth. Although, most emerging market economies benefit greatly from incremental process innovations by re-engineering and refining existing products (Appelbaum et al., 2016).

Figure 4.2: Nanotechnology R&D Investments Worldwide



Source: Cientifica

4.2.4 Collaborative Partnership among Universities and Nanotechnology R&D Firm

Commercialisation of nanotechnology requires an effective innovation strategy which manages large groups of inventors and their stakeholders for exploiting economic gains (Mangematin and Walsh, 2012). R&D policy initiatives have been set up by governments to encourage collaborative partnership between stakeholders in order to boost effective transfer of nanotechnology (Palmberg, 2008). The key pathways for nanotechnology commercialisation are usually the transfer of valuable scientific proficiencies from academia to industry through R&D collaborative partnerships in research clusters and corporate incentives based on tax relief (Rao et al., 2013). The innovative capacity of a country relies on the strengths of the public research laboratories, firms and universities. When well-functioning connections are established among these players, economic growth would be stimulated and many societal problems could be successfully addressed (Weckowska, 2015). The nature of nanotechnology as an early-stage technology requires companies operating within its industry to develop substantial links with universities due to fact that advances in the basic research outpaces developments in technological applications (Rao et al., 2013).

Governments have undertaken various measures to facilitate R&D collaboration between university and industry so as to enhance technological innovation, strategic competitiveness and economic growth (Motoyama, 2014). For a nation to successfully leverage its innovative system in maximising economic development and wealth creation, effective technological transfer must occur through established mechanisms, from scientific discoveries in research laboratories to innovative products in the marketplace (Gibson and Naquin, 2011). The process of transforming scientific discoveries into saleable products is an entrepreneurial skill university research need to acquire. Commercialisation of university research output enhances the sales of innovative high-tech products. Traditionally, R&D investments have been mostly on tangible infrastructural projects such as science parks but nowadays funding collaborative partnerships in high-tech commercial projects has taken more priority due to the expectation for greater returns and better economic impact (Gibson and Naquin, 2011).

Schott (1991) argues that scientific activities are organised by individuals who operate under local, regional, national and international institutions at various levels of spatial proximity and who are in communication with one another in order to create and diffuse scientific knowledge. Schott (1991) further argues that collaboration among scientists from different societies implicitly confirms and explicitly reinforces their belief in the virtues of universal validity as it fosters consensus and facilitates diffusion within the scientific community. The prerequisite for a global diffusion of scientific knowledge is prevalent in the belief in universal validity, wider dissemination, and intensive collaboration (Schott, 1991). According to Mehta et al (2012), the results of systematically assessing international research collaborations in nanotechnology elucidate the associations between national research policies and the development of transnational scientific networks. Mehta et al (2012) argues that as a way of facilitating international collaborations around the globe, governments have provided resources as well as incentives to promote rapid growth and dissemination of scientific knowledge in order to promote indigenous innovation, exploit research synergy, and enhance scientific excellence. Stichweh (1996) argues that the pathway to a contemporary global scientific community usually goes through a transitionary period of strong nationalistic identity in science and technology. Stichweh (1996) concludes that the nationalization of reference groups is compensated in due course by the addition of new processes and systems into an existing scientific community by means of a progressive internal differentiation of science and technology.

Mehta et al., (2012) conclude that in contrast to the European scientific community, emerging economies (such as the Chinese) scientific development was led by state actors and tailored towards the applied sciences. Stichweh (1996) observes that the national scientific institutions usually function as a policy initiative due to the reliance on state funds. Stichweh (1996) suggests that one of the salient determinants of the global interconnectedness of scientific communities is the complex dynamics of the internal differentiation of science. Stichweh (1996) argues that the international interconnectedness of scientific communities is not due to the emergence of a unipolar world of scientists who share a common set of normative and cognitive presumptions; but due to continuous proliferation of ever new societies of scientists with increasingly constrained jurisdictions that standardizes the social and cognitive universe of science in a way which is irreconcilable with the confines of national scientific societies. Katz and Martin (1997) observe that collaboration is usually peculiar to experimental research as it is interdisciplinary in nature and involves the use of large or complex instrumentation such as telescopes and CT scanners. Katz and Martin (1997) identifies the factors contributing to collaboration within scientific communities as: changes in levels of funding; desire for visibility and recognition among researchers; increasing demand for the rationalisation of scientific manpower; rapid specialisation in science; and growing proliferation of science. Lee and Bozeman (2005) observes that the custom among scientific research communities for some years now has been collaboration and this is due to the increasingly complex, very expensive and highly interdisciplinary characteristics of modern scientific endeavours.

Bayh-Dole Act 1980 is a classic example of an economically driven innovation policies which served as a catalyst for transforming scientific productivity in universities and public R&D organisations into innovative products that create high financial performance in the marketplace (Gibson and Naquin, 2011). Policy makers have in recent years put out initiatives to create a 'third mission' for their universities in order to foster a knowledge-based economy where there is an easy transfer of technological discoveries into commercially efficient vehicles (Perkmann et al., 2013). Prioritising, with massive funding, of the application of basic research activities in universities and public R&D organisations into solving societal challenges, is a key factors that has led to more collaborative partnership between academia and industries (Taheri and Geenhuizen, 2016).

4.2.5 Key Performance Indicators of Nanotechnology Advancement

The performance of nanotechnology companies (as per the great commercial promise) provides a useful case study to evaluate the effectiveness of large public R&D investments into promotion of competitive economic advantages in high technology (Appelbaum et al., 2016). The return on R&D investments could be the exponential rise of scientific publications and patent applications originating from research centres and technology laboratories. However, profit-seeking high-tech ventures in emerging markets do not just emanate from the creation of dedicated science parks due to the gap between R&D systems and industries; the difficulty in technology transfer from poor intellectual property right protection; low private VC fund participation to encourage risk-taking; and the deficiencies adequate sophisticated technology managers (Rao et al., 2013).

According to Roco (2011), I describe the key performance indicators of nanotechnology development as the five Ps of nano progress, namely: Papers, Patents, Products, People, and Profits.

4.2.5.1 Scientific Publications

R&D Strategies for enhancing the competitive edge derived from conducting extensive basic and applied research in nanotechnology which is aimed at aligning scientific outputs with business development goals in order to establish a national system of innovation for effective technological transfer (Ikezawa and Ueda, 2013). Smith (1958) initially suggests that multi-author papers can be used as a proxy for measuring the level of collaboration among research groups. Although, Katz and Martin (1997) argue that co-authorships in scientific publications simply provide partial insight into the level of collaboration between two or more researchers due to the fact that; the accurate nature and size of collaboration cannot be clearly determined by survey techniques. Katz and Martin (1997) observes that most policy initiatives are geared at facilitating collaboration not on individual basis but on a higher level of public/private or foreign partnership. Wagner and Leydesdorff (2005) argue that collaboration on an international scale is a network of self-organising researchers with preferential attachments and social constraints. Wagner and Leydesdorff (2005) further argue that the international collaborative networks are very dynamic, rapidly increasing, and highly influential. Lee and Bozeman (2005) observes that collaboration is a robust predictor of publishing productivity when the total number of scientific publication is used as its measurement but when the allocated contribution is weighted into the number of authors, collaboration does not significantly relate to publishing productivity as other factors are kept constant. Katz and Martin (1997) observe that collaboration in scientific communities provides several benefits such as the transfer of knowledge, skills and techniques; the cross-fertilisation of concepts and ideas; the provision of intellectual companionship; and enhancing of the prominence of research work. Ponds et al. (2007) observes that when geographical proximity is high amongst science based technologies between universities, companies and government research institutes; collaboration in scientific research is apparently more likely to be successful since their physical distance is close because of the tacit character of knowledge which requires face-to-face interaction. Ponds et al. (2007) argues that high geographical proximity can compensate for the deficiencies in institutional differences during collaboration; that is, research collaboration concerning different types of organisations is more spatially localised because of shared interest in labour exchange, access to local funding, and mutual trust facilitated by informal contact and interactions. Bozeman and Corley (2004) argues that the closer potential collaborators are in geographical proximity; the more likely there could be an informal communication among them which leads to a collaborative event.

4.2.5.2 Patent Applications

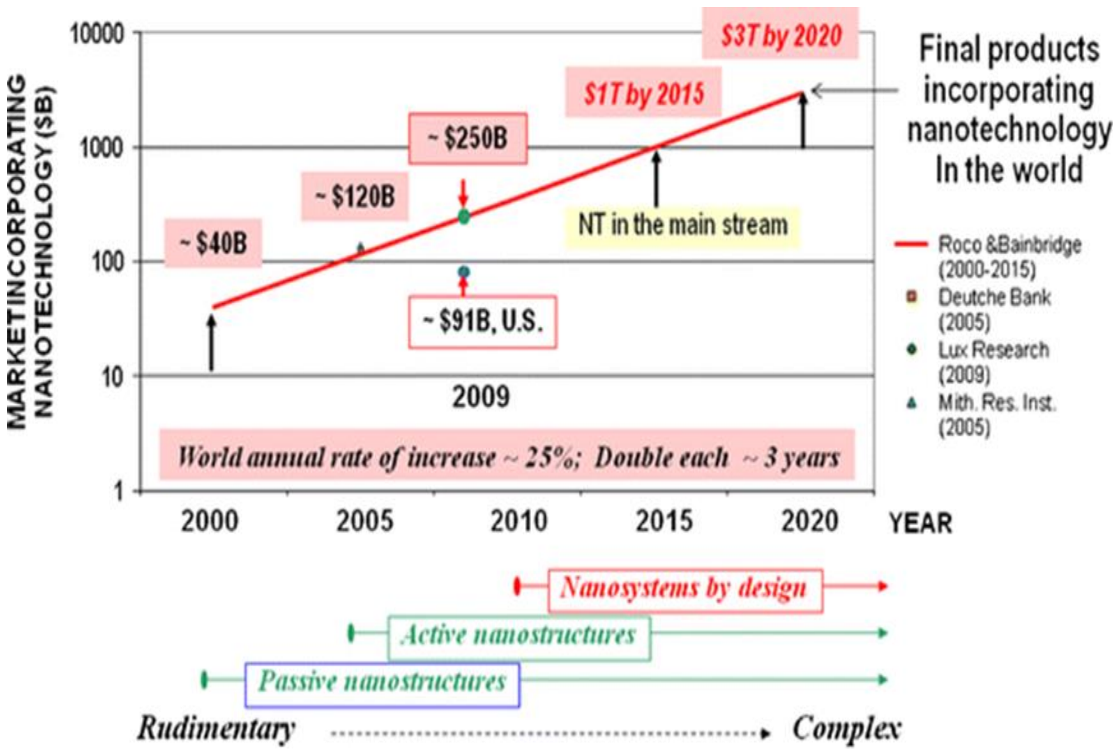
The accumulations of patents in nanotechnologies have been spearheaded by large companies and have preferred to acquire entrepreneurial ventures that are able to overcome technological and market uncertainties through strong financial performance and high growth prospects. Large companies have withheld commercialising some discontinuous innovations which will affect the status quo (Maine et al. 2012). High-tech start-ups and spin-offs boost market competitiveness within their industries by developing patentable discoveries that hold great promise of value creation to end users (Saidi and Zeiss, 2016). Ponds et al. (2007) observe that scientific research is profoundly different from industrial innovation because the former is primarily concerned with adding and diffusing new knowledge into the existing body of knowledge while the latter is more interested in adding to the streams of income from the exclusive rights of hoarding private information. Stichweh (1996) observes that the global exploitation of science and technology by multi-national corporations better describes the much greater rate of growth of international patent applications than the growth rate of national patent applications.

4.2.5.3 Portfolio of New Product Development

One of the most challenging organisational behaviour in the high-tech sector has been shifting from producing scientific publications based on basic research and applied experiments to developing new nano-products within an SME or large corporation with the goals of meeting customer preferences and maximising stakeholders' wealth. In order to grow high-tech industries which promote rapid economic growth, there must be a concerted effort to bring nascent technology that meets consumer demand to the marketplace (Lo et al., 2012). By enabling critical thinking and disruptive innovations, nanotechnology creates new manufacturing and service orientation which produces a myriad of commercial opportunities due to the breaking of existing norms, shift away from previous design and the creativity available to meet consumer preferences (Lo et al., 2012). The ability to create innovative products that eventually attain international brand identification is what truly brings about the commercialisation of high technology (Appelbaum et al., 2016).

The transformational effect nanotechnology could have on most high-tech products in the marketplace would be greater than the sway transistor had on information and communication technology in the 20th century, which makes its pursuit an investment and insurance policy against economic and technological degradation (Linton and Walsh, 2012). Without a doubt, high-tech industrialisation provides the most important avenue for competition among companies and between nations. The advancement of nanotechnology offers a unique source of wealth accumulation through the strengthening of industrial positions in global markets; growth of wide-reaching scientific output and continuous development of innovative products (Ikezawa and Ueda, 2013).

Figure 4.3: Global Valuation of Nanotechnology-related products



Source: Roco, 2011

Nanotech companies that exploit process-based innovations are confronted with higher uncertainty in value chain positioning, greater scope in market coverage, diverse groups for customisation, and frequent changes to target users but this is not the case for nanotech companies developing product-based innovations

(Mangematin and Walsh, 2012). The key problems facing the development of new products are idea generation & evaluation, market orientation and interaction, and uncertainty (Linton and Walsh, 2008). Some of the rewards that emanates from nanotechnology is associated with materials. Since these peculiar materials are employed in the production of numerous high-tech and other products, generating a ripple effect which extends to a broad stream of applications, variety of devices and abundance of new equipment technologies; thereby providing a wealth of business opportunities in many industries (Ikezawa and Ueda, 2013).

Research groups from different fields assemble to carry out studies at the nanoscale in technological hubs in order to incorporate nanotechnology-based materials into existing products and enshrined into new manufacturing processes (Mangematin and Walsh, 2012). Transforming R&D activities into the production of innovative products for consumer use tends to go through different processes such as laboratory experiments, product trials, entrepreneurial financing, and market targeting (Rao et al., 2013). Nanotechnology could be classified into nanomaterials, nanoequipment, nanodevices, and nanobios; which could be adapted to different scientific fields to enhance further innovations (Lo et al., 2012). The emergence of specialist nano-instruments for vital improvements in advanced materials and production techniques could lead to future competitiveness of national industries (Miyazaki and Islam, 2007).

4.2.5.4 Revenue Generation and Long-term Profitability in Nanotechnology Firms

Hi-Tech industries such as nanotechnology, value creation has to be at the forefront of R&D activities because existing methodologies could easily become obsolete and prices of new products can quickly change or rapidly decline in value (Ikezawa and Ueda, 2013). The level of R&D breakthrough, the features of the high-tech product and the scale of meeting consumers' needs drastically improves the likelihood of generating a sustainable revenue stream (Lo et al., 2012). A high level of market acceptance based on value created increases the chances of survival and profitability of high-tech products (Lo et al., 2012). Ex post commercialisation performances of high-tech companies in nanotechnology have rarely been empirically studied (Lo et al., 2012). The profitability of high-tech companies is dependent on their ability to develop or acquire nascent technology and build new products commercially viable in the marketplace (Lo et al., 2012).

4.2.6 Internal and External Determinants of Successful Nanotechnology Firms

The internal and external factors which influence the likelihood of a successful nanotech R&D organisation are important to study because policy makers and business strategists could understand the determinants of nanotech firm performance. Nanotech companies are examined based on the academia/industry links, government sponsorships; VC participation; and foreign affiliations (Rao et al., 2013). Nanotechnology is scientist-driven and in its early developmental stages, although exogenous to an economic system, it is touted as the engine for future growth and linked to industries with high level of R&D intensity (Nikulainen and Palmberg, 2010). There are several cultural dimensions which impede a country's innovative capacity and economic development (Appelbaum et al, 2016). Commercialisation of nano-tech products is hampered by the absence of effective communication links between academia and industry; the low appetite across industries in procuring high R&D expenditure for frontier knowledge; and the incomprehensive laws and regulations due to quality control and safety assessment of nano-materials or nano-processes (Jiao et al., 2016).

It cannot be overemphasized that governments of developing nations have to ensure that their legal systems are open and honest in addition to an educational structure which promotes experimental thinking and scientific recognition with a zero tolerance for corruption (Appelbaum et al, 2016). Management of nanotech companies would be wise to invest in absorptive capacity, new instrumentation and state-of-the-art R&D facilities (Palmberg, 2008). Financial crises increase the need to invest in R&D alliances for the purpose of facilitating economic growth (Gibson and Naquin, 2011). One of the challenges which hamper nanotechnology commercialisation is the lack of academic entrepreneurs who are able to identify business opportunities from their scientific discoveries (Palmberg, 2008). The international scientific community provides the direction for R&D activities in which scientists and entrepreneurs usually through cross-border collaboration and M&A alliances (Rao et al., 2013). The globalisation of the high-technology has led to the mobilisation of world-class talents and internationalisation of start-up capital across industries and between nations (Rao et al., 2013).

4.2.6.1 Venture Capital Investments

Historically, venture capital usually gravitates toward successful high-tech centres where innovative companies seek for early stage and growth financing from sophisticated investors. A prominent economic growth strategy adopted by some developing nations has been to massively fund venture capital activities to assist indigenous high-tech state-owned companies with the resources to re-innovate foreign technologies and adapt established business models in developed nations (Appelbaum et al, 2016). VC investments fill the gap between the scientific productivity of research outputs and the profitability of innovative products in the market place. VCs provide young high-tech companies with the financial aid and commercial expertise required to cross the so-called “valley of death”. However, government R&D funding policies still remain vital in creating a successful national system of innovations (Rao et al., 2013). The conservative investment strategy implemented by most foreign venture capital firms in developing countries are due to the constraints posed by the unstructured regulatory systems and the non-existence of an established legal framework; which reduces risky early-stage financing of undeveloped breakthrough ideas that are ‘far from market’ and focuses on high-tech companies with already marketable products and well-trusted founders (Appelbaum et al, 2016).

4.2.6.2 Organisational Size

SMEs in other high tech industries (such as biotechnology and microelectronics) usually bridge the gap between public research organisations and large companies by specialising in the emergence of innovative ideas from new scientific discoveries through collaborations with pioneering researchers (Mangematin and Walsh, 2012). Start-up firms in high-tech industries devise value creation strategies which connect advances in basic and applied research with solving societal problems for commercial rewards (Maine et al. 2012). The development of nanotechnologies is made by a small number of large clusters of scientists scattered across the globe while the formation of strategic alliances to market nanotechnologies are conducted by large companies and top universities (Mangematin and Walsh, 2012).

4.2.7 Hypotheses Formulation

Innovative and Financial Performance Measurement – Patents, NPD, Revenue and Profits

- *H1*: Nanotech R&D organisations that operate in Common Law countries are more innovative and profitable than those in non-Common Law countries.
- *H2*: Nanotech organisations that operate in countries with higher on export demand for high-tech products have greater innovative and financial performance.
- *H3*: Nanotech organisations that operate in countries with tolerance for ambiguity and uncertainty have more performing nano-products and profitability.
- *H4*: Nanotech organisations that operate in countries with high R&D investments in national nanotechnology initiatives are more innovative and profitable.
- *H5*: Nanotech organisations that operate in countries with high real economic (GDP) growth rate experience greater innovative and financial performance.
- *H6*: Nanotech organisations that operate in countries with high corporate income tax regime have lesser innovative and financial performing nano-products.
- *H7*: Nanotech organisations that receive VC funds are able to secure more innovative and financial performing nano-products.
- *H8*: Nanotech organisations that have high research intensity are able to create more innovative and profitable assets.

4.3 RESEARCH METHODOLOGY

4.3.1 Data Collection

The commercial R&D organisations in my data samples possess different characteristics of nanoscience and nanotechnologies such as the development of nanotubes and nanowires for electrical and biological consumption, plus the use of nanoparticles and the construction of nano-instruments for manufacturing and communication purposes. Specifically, these nanotech R&D firm’s activities include but are not limited to: electrical discharge machining, multi-component injection moulding, electroforming, powder injection moulding, X-ray lithography, nanoimprinting, nanometer-scale measurement, chemical vapour deposition, selective laser sintering and future tooling technology.

In order to assemble the datasets for my study, I first used Orbis database of Bureau van Dijk (BvD) to collect innovative and financial performance metrics on 1,407 nanotech R&D organisations from 2001 – 2015 in the US, UK, Germany, Australia, France, Denmark, Spain, Switzerland, Japan, South Korea, and China. I further extracted numerical and categorical data on their industry classifications, type of financing; amount of nano-products developed; number of patents secured; existence of domestic or foreign strategic alliances; and receipt of government sponsorships. I then merged the data with those from Zephyr database of BvD and contain VC funding and M&A deal information for all the nanotech firms in my sample.

Also, I also collected, from the World Bank database, the annual GDP growth rates and export demand for high-tech products for the relevant countries and during the period of the 2001 - 2015. Likewise, I included the legal origin index developed by La Porta et al., (1999); subsequently modified by Beck et al., (2003); Spamann, (2009); and Cooray, (2011). The legal origins index represents the legal adaptability of countries where nanotech R&D commercialisation takes place. My measurement here focused on the legal dynamics affecting the performance of nanotech R&D organisations.

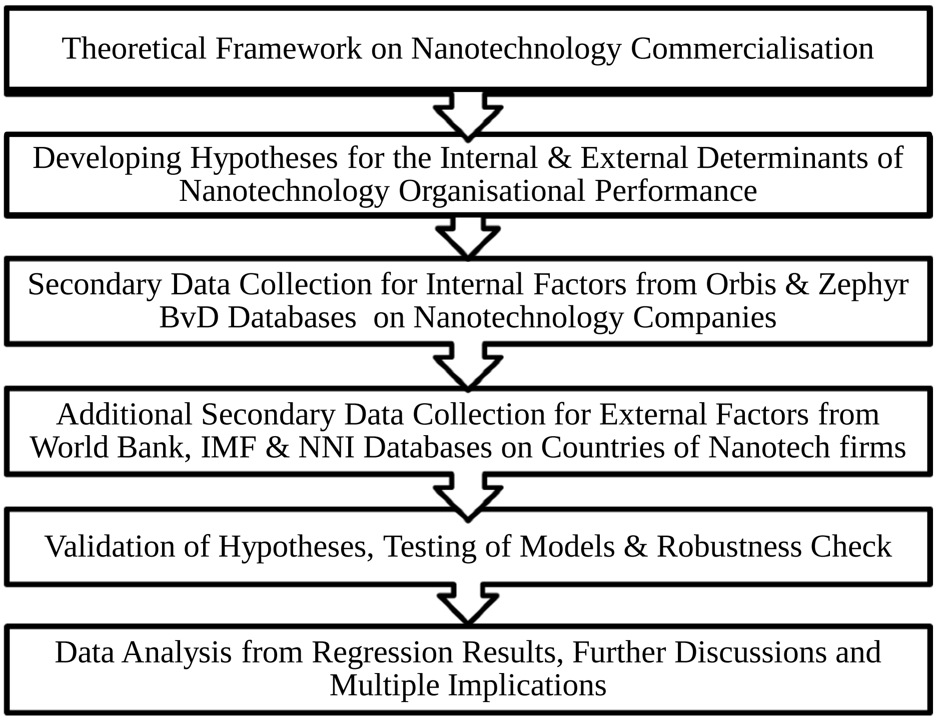
Finally, I added some of the Hofstede's cultural attributes like the uncertainty avoidance and feminine index. Similar to the legal variables, I adopted the national cultural dimension indexes proposed by Hofstede (1983; 1994) for all the nanotech R&D firms in my dataset to provide the measurement for societal attitude towards ambiguity and the public appreciation for feminine values. I then carried out multiple regression and panel data analysis to evaluate my data and provide empirical tests of my research hypotheses.

4.3.2 Research Design

The research design of this study covers the legal, fiscal, cultural and socio-economic external environment of all the nanotech R&D firms in the countries selected from the year 2001 to 2015. The longitudinal dataset of this research report consists of a collection of quantitative and qualitative cross-country nanotech R&D organisational observations from various secondary open sources over a fifteen year commercialisation period. The purpose of adopting this research method is to overcome unobserved heterogeneity problems by controlling for omitted unobserved variable biases that may occur in ordinary multiple regressions (Stock and Watson, 2003).

I adopt a data structure where only key innovative and financial performance metrics that are influenced by certain internal and external factors were considered in this study. In order to observe the determinants of annual nanotech performance at different hierarchy of firm performance; I aggregated nanotech commercial success from each country and regressed the resultant country's organisational observation against a series of country & firm-specific explanatory variables that are also aggregated over time. Also, I examined the correlation coefficients among all dependent and independent variables so as to perform a series of OLS regressions in which I estimated variance inflation factors (VIFs). In addition, I used Hausman Test to observe the correlation between the time-variant and time-invariant variables (Anderson and Hsiao, 1982).

Figure 4.4: Research Outline of the Study



Source: Author

I employed a mixed research method to critically examine the external complexities that affect the performance of nanotech firms. *Figure 1* shows the research outline of this study. The conceptual framework is based on theories of firm performance, national culture influences on inter-organizational behaviour, legal origin as a determinant of financial development, and the international demand for technologically advanced products. These theories provide the basis for constructing and testing my hypotheses to produce empirical results on the internal and external factors that affect the success of nanotech R&D firms during the commercialisation period.

4.3.3 Dependent and Independent Variables

The four dependent variables in this chapter which aim to provide observations on the variations of innovation and financial performance across the US, UK, Germany, Australia, France, Denmark, Spain, Switzerland, Japan, South Korea, China, Russia, Brazil, Turkey, and Israel. Using a similar method adopted by Falope and Ajilore (2006) in this chapter, there are four dependent variables for the four regression models. The first dependent variable is the sum total of the number patents secured by all nanotech R&D organisation in a country and for the given years; the second dependent variable is the sum total of all the new products developed within the nanotechnology industry of a country for the given years; the third response variable is the natural log of the sum of the sales generated in the nanotech industry of a country for the given years; and the fourth is the average profit margin of the nanotech firms in a country for the given years. Each of the dependent variable contains annual observations of nanotech firm performance in 15 countries for the time period of 2001 – 2015. The linear relationship is depicted below:

$$\text{Nano - Performance}_{i,t} = \alpha + \sum_{m=1}^{M} \beta_m \, C_{m,i,t} + \varepsilon_{i,t}$$

Where[3]*:*

- Nanotech firm Performance = Patents, NPD, Revenue and Profit Margins in nanotech R&D organisation in the country (*i*) for each year (*t*).

The independent variables remained, for the most part, the same in the four models used in this study. They were employed to determine the factors which that influence

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[3] *Where M is lag length that varies with t; Cm,i,t are legal, cultural, economic, technological & fiscal factors with some control variables during year t. (Thiengtham, 2010).*

the innovation and financial performance of nanotech firms across countries during the commercialisation era. Among the variables which help explain the variations in the success of nanotech firms across the globe include: the country's annual R&D expenditure (% of GDP); entrepreneurial indexes; corporate tax rates; level of export demand for high-tech products; and the economic growth rates (collected from World Bank Open Data from 2001 - 2015) and the legal origins of countries (dummies for Scandinavian, French and German Civil Law – La Porta et al., 1999); the Hofstede's national culture indexes for uncertainty avoidance, power distance, and Masculinity vs Femininity. These are the explanatory variables for this chapter are a variety of country factors and organisational determinants; that were used to evaluate the degree to which its periodic changes affect nanotech firm performance. *Table 4.2* shows the list and describes the variables and their expected relationship with the observed variable in the panel data models.

Table 4.2: Key Variables, Expected Relationships, and Brief Description

S/N	Variables	Effects	Description
1	Liquidity	+	The average ratio of the ability of nanotech firms in a country to meet their financial obligations when they fall due.
2	Employee Turnover	+	The average ratio all nanotech firms ability to retain key scientists in a given country for the stated years.
3	Industry Diversity	+	A dummy variable (1) indicating the multiple industry affiliation of nanotech firms and (0) otherwise.
4	Long term Orientation	+	A dummy variable (1) indicating long term strategic planning of nanotech firms and (0) otherwise.
5	Legal Origin Index	_	Nominal variable coded (1-3) for countries with French, German and Scandinavian Civil Law Origins and English Common Law origins (0) as the base.
6	VC Investments	+	The natural log of the average annual VC invesments into nanotech firms for a country.
7	Masculinity(vs) Femininity	+	Hofstede's cultural index of societal attitude towards feminine values in countries selected in my sample.
8	Uncertainty Avoidance	_	Hofstede's cultural index of tolerance for uncertainty and ambiguity in countries selected in my sample.
9	Power Distance	_	Hofstede's cultural index of power distance in countries selected in my sample.
10	Entrepreneurial Index	_	Annual index of the health of the entrepreneurship ecosystem in countries selected in the sample and for the given period of time.
11	Export demand for High-Tech Products Index	+	The country's average export demand for high-tech products from 2001 – 2015.
12	Corporate Tax	+	The percentage of corporate taxes for nanotech firms

	Rate		in each country for the given period.
13	Economic Growth	+	The average rate of annual GDP growth for countries in the given period.
14	R&D Expenditure (% of GDP)	+	The average annual R&D expenditure as a percentage of GDP for the countries and in the given years.
15	Government Subsidy	+	A dummy variable (1) represents receipts of government subsidy and (0) otherwise.
16	Organisational Size	+	The net assets divided by the number of employees in a nanotech R&D organisation in a given country.
17	Solvency	+	The average financial for all nanotech firms in the sample countries for the given years.
18	R&D Intensity	+	The average expenditure by all nanotech firms in each country on research and development.
19	Foreign Affiliations	+	A dummy variable (1) for those nanotech firms that are associated with foreign partners.
20	Total Assets Growth	+	The average annual growth rate of the total assets of nanotech firms in a given country.
21	Independent Board	+	A dummy variable (1) represents independent board and (0) otherwise.

Key variables for my study and expected relationships in my data analysis

4.3.4 Control Variables

I controlled for the organisational size and average VC investments into nanotech firms in the country in which they operate. Dummy variables were employed to quantify the categorical variables in order to enrich my dataset when running the regressions while the natural logarithm was used to scale the large amounts. Controlling these variables helped me better understand the effects of my independent variables on the observed variable. These variables are held constant in order to effectively evaluate the relationship that exists between nanotech performances in a country and the legal, regulatory, cultural and fiscal external environments.

4.3.5 Multi Regression Models

Since the performance of the commercial activities of nanotech R&D firms can be observed in several ways, I developed four multiple regression models which are aimed at incorporating the different forms of innovative and financial performance of nanotech R&D firms. I used multiple linear regression models to derive OLS estimates which that minimize the squared residuals of best fit. I specify my multiple regression models for this research study in the equation 2 below:

$$\gamma_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki} + \varepsilon_i$$

Where γ is the dependent variable for the *i*th observation, which is the number of patents in the nanotech firm before the start of commercial activities; β_0 is the constant or intercept which that depicts the relationship that exists without the inputs of my explanatory variables. β_1 to β_k are the parameters and X_1 to X_k are the coefficients, while ε is the error term which that describes the random element of the linear relationships between explanatory and response variables.

4.3.6 Panel Data Analysis

According to Berrington (2006), panel data is frequently used to overcome the limitations of static cross-sectional data such as unobserved variable bias, endogeneity bias and indeterminacy over the sequencing of the causal mechanism. Panel data has been employed in this report to tackle the time ordering of variables and to detect the trajectories over time in order to accommodate the possibility that observations for the same unit over time is unlikely to be independent of one another.

4.3.6.1 Mixed Model Approach

Mixed model provides a flexible platform for multi regression analysis because it generally permits the modelling of a vast array of correlation patterns. Mixed model is the combination of fixed and random -effects which provides the error term with an interesting structure. Seltman (2012) defines mixed model as *'the panel dataset that allows regression coefficients to vary across values of a higher order variable'*. As proposed by Wooldridge (2008), the model below provides the equational structure for analysing a panel dataset; it is the fixed effects transformation.

$$\ddot{\gamma}_{i,t} = \beta_1 \ddot{X}_{i,t1} + \beta_2 \ddot{X}_{i,t2} + \cdots + \beta_k \ddot{X}_{i,tk} + \ddot{u}_{i,t}\,, \qquad t = 1,2,\ldots,T.$$

Where:

- *ÿ* = is the time-demeaned data of the dependent variable *y;*
- *ẍ* = is the time-demeaned data of the independent variables x1, x2 … xk;
- *ü* = is the time-demeaned data of the error term;
- *i* = No. of Countries; *t* = No. of Years;

I adopted fixed-effects since I am interested in evaluating the impact of both internal and external variables which vary over the commercialisation period of nanotechnology. I used fixed-effects to explore the relationship between predictors and response variable within a country. While I assume that each country in my dataset possesses its own idiosyncratic characteristics that could influence some of the independent variables, I control for this by assuming that the correlation between a country's error term and the predictor variables. The purpose of applying fixed-effects is to eliminate the impact of time-invariant features in order to evaluate the net effect of the predictors on the response variable. Hausman test was carried out to check if the error terms are correlated. The equation for the fixed effects model is:

$$\gamma_{i,t} = \alpha_i + \beta_1 X_{i,t} + U_{i,t}$$

The key to resolving the problem of correlated within subject errors in this research study is to let each subject have their individual intercept and slope randomly deviating from the mean intercept for each country (Seltman, 2012). I would aggregate nanotech firm performance by country and regress the resultant country observation against a series of country-specific explanatory variables that are also aggregated over time. The linear relationship between nanotech performance and changing firm- and country-specific factors are shown below:

$$\Delta Nano - Performance_{i,t} \,/\, Firm\ Size_{i,t} = \alpha + \sum_{m=1}^{M} \sum_{s=0}^{1} \beta_{m,s}\, \Delta C_{m,i,t-s} + \varepsilon_{i,t}$$

Where:

- Δnanotech firm success$_{i,t}$ is the % change in number of patents/NPD/Revenue/PBIT in country *i* during year *t* (i.e. From year t-1 to year t), *s* is lag length which varies with *t*.

- $C_{m,i,t-s}$ are changes in the changes in corporate income taxes, indicator variables that measure positive/negative changes in a country's economic growth during year *t* and the prior year.

4.3.7 Handling Collinearity problems

Naes and Mevik (2001) argues that Collinearity problems significantly affect the prediction and classification ability of the panel data; in terms of instability of the small eigenvalues and the consequences this may have on the empirical inverse covariance matrix which is involved in regression. I would examine the correlation coefficients among all dependent and independent variables so as to perform a series of OLS regressions in which I estimate variance inflation factors (VIFs). Also, I conducted Hausman Test to examine the correlation between the time-variant and time-invariant variables.

4.4 DATA ANALYSIS

The extant empirical studies on the performance of nanotechnology activities have generally concentrated on the factors which influence the scientific publications and patent applications of researchers and R&D organisations. Also, another common approach has been the assessment of the new nano-products in relation to meeting consumer preferences where nanotech R&D firms marketable goods and services which generate revenue that can be sustained over a period of time. In this study, I analyse the success of nanotech firms during the period of intensive R&D initiatives which boosts the commercial prospects of nano-products in the market place.

4.4.1 Descriptive Statistics

Table 4.3 below shows the summary statistics for this research report. It depicts the mean, standard deviation, minimum and maximum values as well as the number of observations for each variable. The total number of nanotech firms is 1,407 and is used to provide sufficient framework to analyse the success of these high-tech firms.

The number of patents and new nano-product developed are converted to natural logarithm to reduce the influence of outliers and provide a proxy for the innovative performance of nanotech firms. Also, the domestic or foreign affiliations of the nanotech firms were taken into account by considering the location of their manufacturing base; a dummy variable is used to indicate cross-border effects on their success. In addition, the sectors to which the nanotech companies belongs helps to identify the different industry which they operate in.

Table 4.3: Descriptive Statistics and Correlation Matrix

	Variables	Mean	Std. Dev	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	Liquidity	25.11592	9.2290806	1																				
2	Employee Turnover	2.056414	6.96266	0.6211	1																			
3	Long term Orientation	29.19755	18.5603	-0.0923	0.0316	1																		
4	Industry Diversity	3.90517	20.51651	0.1765	0.1933	0.3489	1																	
5	Legal Origins	18.01848	1.61193	-0.1211	-0.2475	0.1087	0.0605	1																
6	VC Investment	0.7063369	0.4556155	0.0314	-0.3541	0.1985	-0.2475	0.1697	1															
7	Masculinity vs Femininity	55.802318	4.2976627	0.3612	0.3021	0.0308	-0.3541	0.0195	0.2395	1														
8	Uncertainty Avoidance	47.857805	8.9280148	-0.1388	-0.0761	0.0474	0.3021	0.2779	0.0191	0.0314	1													
9	R&D Intensity	3.063875	7.596558	0.0938	0.1989	0.5093	0.0579	0.3591	-0.139	-0.657	0.1697	1												
10	Total Assets growth	15.379414	8.215785	-0.1649	0.0143	-0.304	-0.0808	0.1996	-0.33	-0.059	0.0195	-0.029	1											
11	Export Demand for High-Tech	40.719289	4.0501818	0.1697	-0.3838	0.1481	0.3088	0.5093	0.2496	-0.029	0.1459	0.1745	0.0249	1										
12	Entrepreneurial Index	12.68769	105.838	0.0195	0.1124	0.1958	0.0474	-0.304	-0.174	-0.086	-0.243	0.0147	0.3237	0.0195	1									
13	Economic Growth	5.218258	35.8802	0.2779	-0.2663	0.0424	0.3511	0.1481	0.3237	0.0516	-0.222	-0.155	0.3088	-0.081	-0.194	1								
14	Power Distance	159.0521	202.8128	0.0999	-0.1944	0.3591	-0.0104	0.1958	-0.174	-0.162	0.0605	0.2395	0.0474	0.3237	-0.165	0.1958	1							
15	Solvency	38.56146	38.15551	0.3271	0.0443	0.0984	0.0165	0.0424	0.0316	-0.189	-0.248	0.0191	0.3511	-0.174	0.1697	0.0424	-0.174	1						
16	Government Subsidies	0.8106646	0.3919263	0.0727	0.0101	0.1745	0.0474	0.3591	0.1933	0.4543	-0.354	-0.008	-0.01	0.0316	0.0195	0.3591	0.3237	0.1765	1					
17	Foreign Affiliations	0.2990726	0.4580287	-0.1051	0.3088	-0.1741	0.1765	0.0984	0.1367	0.1448	0.3021	0.2478	0.0165	0.1933	0.2779	0.0984	-0.174	-0.121	0.1124	1				
18	Corporation Tax Rate	0.0942813	0.2923326	0.0121	0.0474	0.3237	-0.1211	0.1745	0.3488	0.2933	0.0579	-0.139	0.2779	0.1367	0.0999	0.1745	0.0316	0.0314	-0.266	-0.304	1			
19	Organisational Size	13.44915	50.29794	0.0195	0.3511	-0.1741	0.0314	-0.174	0.0573	0.1901	0.5283	0.0938	0.0999	-0.042	0.0424	0.1459	0.1933	0.0314	-0.194	0.1481	0.1124	1		
20	Independent Board	0.028471	0.57466	-0.1007	0.1721	0.1851	0.1985	0.0145	-0.354	0.0556	0.0195	0.2779	0.2129	0.0579	0.3271	0.1124	-0.058	0.2009	0.3484	0.1481	0.2779	0.3021	1	
21	R&D Expenditure	4.82355	20.48787	-0.0947	0.1958	0.1022	0.0308	0.0463	0.3021	0.0326	0.3591	0.0121	-0.417	-0.081	0.0727	-0.266	-0.118	-0.036	0.7645	0.1958	0.0999	0.1548	0.1801	1

Table 4.3 shows the descriptive statistics and correlation matrix for this Chapter

Table 4.4: Multiple Regression Coefficients

Internal Dynamics	**Model 1 (Patents)**	**Model 2 (NPD)**	**Model 3 (Sales)**	**Model 4 (Profits)**
R&D Intensity	0.0122**	0.0125**	0.0121**	0.0280***
	(2.61)	(2.81)	(2.76)	(4.11)
Organisational Size	0.00206*	0.00213**	0.00241**	0.00149
	(2.49)	(2.72)	(3.08)	(0.87)
Employee Turnover	0.0052*	0.00627*	0.000473	-0.00637
	(1.20)	(1.52)	(0.11)	(-1.01)
Solvency	-0.00579	-0.00429	0.000344*	0.0000464*
	(-1.40)	(-0.70)	(0.7)	(0.06)
Liquidity	-0.00455	0.000354	0.0192**	0.0255**
	(-1.55)	(0.69)	(1.37)	(1.15)
Total Asset Growth	-0.00234	-0.00211	0.00147*	0.00364*
	(-1.04)	(-0.99)	(0.69)	(0.88)
Independent Board	0.00887	0.0101	0.00572*	0.00669*
	(1.35)	(1.62)	(2.06)	(2.40)
Government Subsidy	0.00196	-0.000597	0.0125*	0.0316*
	(0.43)	(-0.14)	(2.00)	(2.16)
VC Participation	0.022	0.000209	1.127***	1.118***
	(1.58)	(0.43)	(3.74)	(3.54)
External Dynamics				
R&D Expenditure	0.596***	0.438**	0.434**	0.144
	(3.5)	(2.68)	(2.67)	(0.65)
Technological Adv.	0.479*	0.309*	0.345**	0.531**
	(1.96)	(1.32)	(1.48)	(1.87)
Corporation Tax	0.123	0.0904	-0.0278*	-0.0646*
	(0.67)	(0.52)	(-0.15)	(-0.27)
Economic growth	1.312***	1.188***	1.177***	0.912**
	(5.26)	(5.01)	(4.96)	(2.97)
Entrepreneurial Index	0.244	0.299*	0.253**	0.396**
	(1.64)	(2.12)	(1.79)	(1.93)
Foreign Alliances	-0.481**	-0.300*	-0.285	-0.16
	(-3.09)	(-2.00)	(-1.89)	(-0.81)
Legal Origins	0.186**	0.238*	0.244*	0.296*

	(1.24)	(1.67)	(1.71)	(1.53)
Uncertainty Avoidance	0.00929** (1.73)	-0.108 (-0.19)	-0.14 (-0.50)	0.599** (1.15)
Femininity Values	0.00193 (0.04)	-0.154 (-1.05)	0.0466* (0.20)	0.484* (0.90)
Power Distance	0.0873*** (4.71)	0.0779* (1.88)	0.615*** (6.75)	1.547** (1.91)
Long-term orientation	0.765** (1.30)	0.590* (1.31)	0.778*** (2.48)	0.745** (0.173)
Industry Diversity	0.00863 (4.12)	162.3 (0.11)	0.447*** (5.37)	0.00823** (1.84)
Constant	17.39*** (49.67)	18.81*** (47.61)	18.18*** (43)	15.98*** (20.59)
Observations	1407	1407	288	288

t statistics in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Also, where the national culture of countries is that masculine values heavily dominate over feminine ones, there are usually fewer performing dimensions of nanotech companies. Regulatory barriers, as well as low female participation in science and technology, are possible reasons for these cultural effects on the performance of nanotech R&D ventures. My results show that a country’s cultural attitudes concerning uncertainty and feminine values affect the way nanotech R&D companies are managed. A high intolerance for ambiguous nanotech R&D ventures within a society brings about centralized governance mechanisms, which lead to less innovative outcomes. Likewise, a dominant masculine culture within a society means that nanotech R&D ventures tend to have centralized governance mechanisms that seek to achieve organizational objectives at the earliest possible time frame.

Also, I find that the economic expansion of a country enhances the all performance dimensions of nanotech R&D ventures, due to the additional sources of funds available for R&D expenditure. As expected, a high GDP growth positively influences the number of patents secured, the amount of new nano-products developed, the sales revenue received from marketing these high-tech products and the level of profitability in the overall commercial operations among nanotech R&D ventures.

Also, a high GDP growth rate is more likely to have a positive effect on the time spent in developing innovative assets by nanotech ventures, as funding from R&D expenditure increases from government agencies. Similarly, an active VC fund manager's participation in the strategic activities of nanotech firms significantly adds to the successful commercialization of nanotech companies; I believe this is in order to monitor and supervise the R&D projects so that financial performance is attained as the earliest possible time.

Larger nanotech companies are capable of performing better than their SME counterparts, because they have greater financial resources and better human capital (Zheng et al., 2014). The innovative assets of these large nanotech R&D firms negatively affect their profitability since they hoard secret commercial information for competitive advantages. High export demand for technologically advanced products and services tend to have a significant effect on the sales revenue generated by nanotech companies. My results show that legal origins significantly affect the governance mechanisms of nanotech R&D companies. I find that nanotech firms that carry out their collaborative R&D projects in countries with French and German Civil Law origins have centralized governance mechanisms, compared with English Common Law origin, because of the need to tightly control the activities of their partners to adhere to stringent regulatory policies. Also, countries with French Civil Law origins are likely to weaken the value networks of nanotech R&D companies, compared with those with legal origins in English Common Law countries.

4.4.3 Discussion of Findings

I identify possible opportunities and challenges for policy-makers and organizational strategists to exploit or guard against, with the objective of enhancing various dimensions of innovative and financial performance of nanotech R&D ventures. Countries with French Civil Law Origins have a less rigorous legal system (La Porta et al., 1999). Nanotechnology is an emerging technology that has few laws regulating its industry. The French and German legal systems provide a lesser degree of flexibility for securing patents and higher level of predictability for estimating litigation outcomes. This makes it less profitable for nanotech R&D companies, because there are lots of regulations that either restrict the nature and scale of research exploration and commercial exploitation or that could pose a huge threat and raise the possibility of large losses – unlike the English legal system, where there is an inherent rule to have minimum standards of care.

The level of tolerance for uncertainty within a nation reveals their cultural attitude towards risks and ambiguity (Sriwindono and Yahya, 2012). A country with a high uncertainty avoidance index is more likely to have rigid belief systems that are intolerant of unorthodox and risky behaviours, because the majority of people with such cultural values are sensitive to, and feel uncomfortable with, unstructured or changeable environments. However, a low uncertainty avoidance index evinces that members of a society are more likely to be forbearing towards ambiguous or uncertain R&D ventures, because they are entrepreneurial in nature and are likely to feel comfortable in risky and less structured environments. In these countries, nanotech R&D firm managers can take advantage of the politically active and informed populations by making quick decisions that exploit innovative concepts.

Feminine values are another important cultural trait to seriously consider, as this trait affects the some of the dimensions of nanotech company performance. A high proportion of female involvement in science and technology within a country would more likely increase the strength of value networks and reduce the innovative capacity of nanotech R&D ventures. In contrast, a more dominant male presence usually leads to ego-oriented inter-firm relationships that promote fierce competition and focus on profit maximization, irrespective of the impact on the external environment. Cultural values do not easily change in the short run and are usually passed from one generation to another, so it is expedient for policy-makers and corporate strategists interested in nanotech firm performance need to understand the possible implications and predictable behaviours relating to risk tolerance, procedural controls, and adherence to norms within a community that they operate in, so as to promote discussions that alleviate unproven claims, improve negotiating processes, and reduce litigation costs (Hong, Heikkinen, and Blomqvist, 2010). In knowledge-based economies, the expansion of economic activities usually leads to a rise in R&D expenditures. Most R&D organisations normally obtain massive funds from research councils and industry partners to finance their R&D ventures, with the aim of building innovative high-tech industry and foster regional economic growth (This corresponds with the findings of Bilbao-Osorio and Rodriguez-Pose, 2004;

Guerrero, Cunningham, and Urbano, 2015). Periods of economic growth positively affect the innovative and financial performance of nanotech R&D ventures, as a result of the availability of several funding prospects, the prevalence of commercial opportunities, and the rise in labour participation.

An increase in the external R&D activities of high tech firms has resulted in the rapid rise of inter-organizational relationships, which lead to patent licensing agreements and the development and production of new products. The commercialization of R&D activities via university-industry collaborative partnerships has brought not only economic development but also the technological advancement of nations, due to the international demand for their high-tech products, which are usually emerging or disruptive know-how. Having exclusive rights to an innovative product in the form of a patent provides nanotech firms with the required protection for their intellectual property and encourages more R&D projects in the future. As a result of globalization, many countries have been able to unlock localized industries by taking advantage of new and existing export opportunities for high-tech products and services around the world (Mehta et al. 2012). World trade organization has alleviated most barriers and challenges in international commerce, as advanced nations and large corporations are able to attract high-skilled labor and sophisticated investments into emerging and disruptive industries to provide technologically-advanced products and services for worldwide consumption. The export demand for high-tech products evinces the level of technological advancement in a country. Most MNCs have their internal R&D capabilities at their headquarters, and many external R&D projects are organized in their home country. Nanotech firms that operate in advanced technological nations are more likely to sell their newly developed innovative products to international markets. They are also more likely to spend less time in collaboration, due to their centralized governance mechanisms and comprehensive value networks.

A high financial position or status of nanotech firms equips R&D project managers with sufficient tangible and intangible resources to engage into complex collaborative partnerships which yield innovative performing outcomes. In order words, a highly profitable, solvent and liquid nanotech firm would be able to form large collaborative partnerships with international reach so as to coordinate useful networks which are more likely to contribute significantly to the development of new products during commercialisation. The operations of a financially stable nanotech firm provide implicit guarantees and explicit endorsements that the R&D products would likely succeed due to the availability of additional resources which could be deployed if needed. For instance, a high solvency in nanotech firms creates a huge valuable financial position which is able to ensure initial funding from long-term reserves and relative stability in R&D operations during constricting economic periods and in times of rising unexpected litigation costs. Also, financial institutions and government agencies are willing to participate in the funding of nanotech R&D projects when the firms in collaborative partnerships have serviceable debt levels which do not bring additional economic liabilities or legal constraints. Nanotech firms with evidence of strong past financial performance in terms of profitability and liquidity are placed on a higher status during negotiations as weaker or smaller new partners are happy to make some concessions in other to be part of an exclusive R&D project which has a good chance of success. In general, some financial performance indicators could provide a significant insight on factors that influence the innovative performance of R&D projects. The presence of VC funding in collaborative nanotech R&D projects means that a much specialised financial expert would provide useful counsel on the most commercially viable path to pursue in the quest to create an innovative product which meets profitable consumer needs because of the active participation and strong influence VC fund managers usually obtain through contractual obligations.

The ability of a nanotech firm to retain previous knowledge and integrate it into their current operating system means that new external knowledge would likely be efficiently managed to stimulate innovative outcomes because the best industry practice and successful previous processes would be adopted effectively to take advantage of key business opportunities which enhance the innovative performance of nanotech R&D firms. A critical issue here could be developing a governance mechanism which provides nanotech R&D project managers with a reasonable level of discretion in making key resource reallocation decisions and gives their financial sponsors adequate monitoring tools to reduce information asymmetry. Previous experiences provide ample ammunitions to R&D project managers in the form of collaborative knowledge. Having an awareness of what to look out for and guiding against common pitfalls are some of the advantages of obtaining useful previous experiences in R&D collaboration. However, R&D project managers should be mindful of the fact that previous experience is only a guide and do not necessarily affect future R&D ventures. This means that old organisational procedures and strategies should be moderated to accommodate new types of foreign partners and new ways to maximize the contributory effects on the innovative performance of nanotech R&D projects. It must be emphasized that adequate documentation of previous collaborative partnerships is imperative because of the need for constant referrals on what works or on what should be avoided. Innovative assets are considered as a main determinant of innovative performance in R&D ventures.

4.5 CONCLUSION

In this final section, I would identify possible opportunities and challenges for policy makers and organisational strategists to exploit or guard against; in order to enhance the innovative and financial performance of nanotech companies.

4.5.1 Managerial Implications

A large number of foreign partners in nanotech R&D collaborative partnership provide a bundle of diversification benefits which influences the creativity and productivity in R&D projects. However, foreign alliances only facilitate the development of new products and do not significantly affects the securing of patents or the profitability of newly developed products. It means that R&D project managers or organisational strategists must focus on unique procedures which integrates each aspect of the collaborative partnership in such a way that all parties involved are required to understand and appreciate the legal and commercial external dimensions of the R&D ventures so that early profitable opportunities are identified, legal barriers are mitigated, intellectual property rights are secured and future market trends are recognised and exploited.

The value network of a collaborative partnership in nanotech R&D projects is considered to be very strong when it is deeply integrated vertically and horizontally from their supply-chain in order to meaningfully enhance the innovative performance of R&D projects. However, a strong value network does not necessarily mean that new products will be developed because of the complexities in nanotechnology production. Nonetheless, R&D project managers are required to maximize human resources in a way that circumvents the challenges and riskiness of developing new products which are safe and viable in the market place. This would require having a structural procedure in place which seeks to facilitate timely interactions among all partners in such a way that the conceptualisation of new products are harmonised at inception and strategically evaluated by top managers so that adequate resources could be channelled into the development of these new products on time.

4.5.2 Key Recommendations

4.5.2.1 Policy Recommendations

Nanotechnology is an interdisciplinary field that requires a great deal of physical closeness among R&D partners, who use very complex instruments to develop innovative products and services through a decentralized system of governance that minimizes contingency risks (Steinmo and Rasmussen, 2016). The lack of a concentration of nanotechnology experts within a local scientific community in the past has created a need for international collaborations with a distributive organizational structure, in spite of the drawbacks from their geographical closeness (Kabo et al., 2014). Nanotech R&D ventures usually involves large funds and expertise, which divert managerial resources away from internal R&D projects. Institutionalizing collaborative partnerships is extremely challenging, because R&D projects demand new organizational structures and procedures that harness available resources to achieve set objectives.

As a discontinuous innovation-based technology, nanotechnology has few laws that regulate its industry. It requires highly skilled scientists from different disciplines to work in close proximity and operate complex instruments to create innovative new products within a specified period of time. Nanotechnology is an interdisciplinary field that requires a great deal of physical closeness among R&D partners, despite the advancements in ICT as well as the free movement of capital and labour across Europe. Globalisation has helped many countries to unlock localized industries, by taking advantage of new and existing export opportunities for high-tech products across the globe. Universities involved in discontinuous innovation-based R&D projects have specialized interdisciplinary centers, which are capable of collaborating with more industrial partners because of their access to additional financing. Patents and other intellectual property should be used to meet the needs of low-end and prospective customers. Also, academic institutions are now benefiting from the legitimate financial considerations of supplementing patents with publications.

Advanced nations and large corporations are able to attract high skilled labour and sophisticated investments into emerging and disruptive industries to provide technologically advanced products and services for worldwide consumption. Also, a high proportion of female involvement in science and technology within a country would likely increase the strength of value networks and reduce the period of collaborative partnerships in nanotech R&D projects. The existence of VC funding in nanotech R&D projects indicates that there are significant commercial opportunities available, and that entrepreneurial prowess is prevalent in such collaborative partnerships. Certain legal systems, which provide both a greater level of flexibility for securing patents and a higher level of predictability for estimating litigation outcomes, are likely to be more appealing to nanotech R&D project managers, because there is little regulation restricting the nature and scale of research exploration and commercial exploitation or that could pose a huge threat and the possibility of large losses. Also, countries with high uncertainty avoidance index are more likely to have rigid belief systems that are intolerant of unconventional and hazardous behaviours, because the majority of the population feel anxious about unpredictable environments. A low uncertainty avoidance index evinces that members of the public are more likely to be tolerant towards ambiguous or uncertain R&D ventures because of their entrepreneurial mind-set which is at ease with risky and unstructured environments.

4.5.2.2 Sales (Marketing Strategy) Recommendations

Nanotechnology will underpin the future global economy and knowledge of its commercial possibilities along with the environmental impact has to be fully explored and exploited to the level of its technological development (Mangematin and Walsh, 2012). The development of nanotechnology provide vast reservoir of latent innovative capacities which create business opportunities for manufacturing firms and a substantive remedial solution to the gradually hollowing-out of core competencies and existing industrial prowess in advanced countries (Ikezawa and Ueda, 2013). Another level of competition in nanotechnology occurs at the setting of optimal management policies besides the scientific and technological dimensions

(Nicolau, 2004). Nanotechnology would cause the next surge in technological development which would be characterised with components of radical innovation across various fields (Maine et al. 2012). Commercial motivations is likely enhanced in nano-scientists as their research activities are applied in nature, receive huge public funding and have little regulatory barriers (Nikulainen and Palmberg, 2010). A collaborative partnership among nanotech organizations with foreign designations could be employed as a market entry corporate strategy into tightly controlled nanotech industries to circumvent regulatory constraints.

4.5.2.3 Ethical Recommendations

The fierce global competition in the development of nanotechnologies raises legitimate concerns whether ethics could become a casualty in the race for technical superiority. So it is incumbent of industry participants to undertake self-examination for early risk identification and avoidance of harsh regulatory measures (Linton and Walsh, 2012). The impact of nanoscience and nanotechnologies has been keenly highlighted by prominent individuals, interest groups and even in the movies, so as to promote thorough risk assessments and further regulatory activities, and ensure that a high level of ethical standards are employed during commercial development. These assurances have significantly reduced the British public's concerns about the ambiguities in nanoscience and nanotechnology. Therefore, it is imperative for nanotech firms in countries with an English Common Law origin to take into consideration the additional cost required to make risk assessments about their R&D ventures publicly available, in order to enhance public awareness and reduce the general intolerance for uncertainties associated with nanotechnology.

Chapter 5: Financial & Non-Financial Determinants of the Exit Performance of Venture Capital (VC) and non-VC backed Nanotechnology Portfolio Companies

5.1 INTRODUCTION

5.1.1 Brief Overview of Venture Capital

At the turn of the 20th century, venture capital (VC) was mostly in the domain of wealthy individuals and families such as J.D. Rockefeller, J.P. Morgan and the Wallenberg's. They all sought to acquire strategic but also lucrative private companies in order to gain significant control of particular industries within the U.S. economy. After the stock market crash of 1929 and subsequently the great depression that ensued in the 1930s; large solvent corporations with massive cash reserves were able to take advantage of the shutdown of the financial system by purchasing bankrupt industry-leading companies and revolutionary business ventures at their 'fire sales' value.

According to Hsu and Kenney (2004), the modern origins of VC could be traced to the formation of the American Research and Development Corporation (ARD) in 1946 by Georges Doriot, who is regarded as the father of venture capitalism. After World War II[4], the United States government was eager to promote job opportunities for returning veterans and others alike in order to stimulate economic activities. Consequently, financing start-ups became even more essential at the time; with the need for a specialist organisation to identify and fund innovative concepts, unknown technologically advanced products and superior industry services. The United States is generally regarded as the birthplace of VC activities; and it is no surprise that it has the most sophisticated VC industry in the world. A huge portion of the global VC industry operations can be attributed to the entrepreneurial spirit prevalent in the United States.

Traditional financial institutions such as banks are unable or unwilling to finance and monitor high-tech entrepreneurial activities due to their complexities, riskiness, illiquidity and untested markets and/or products. Over the years, VC has played an

[4] Lerner (2002) argues that ARD funded new technologies developed during World War II.

instrumental role in financing companies with little or no economic track record in order to capitalise on revolutionary discoveries in emerging and disruptive technologies like information & communication technologies (ICT) and bio-nanotechnology. During the Dot-Com economic boom in the Mid 1990s, for instance, VC firms around the world provided seed finance and other kinds of support like accounting, marketing, legal, and industry network to lots of young IT companies so as to capitalise on the huge gains from the sale of these IT stocks through various exit platforms. Thiengtham (2010) describes ‘venture capital as a long term investment in equity capital of new, potentially high growth, and non-publicly traded companies that produce new and innovative products and services for new customers in new markets in return for capital gains rather than interest income and dividend yields’.

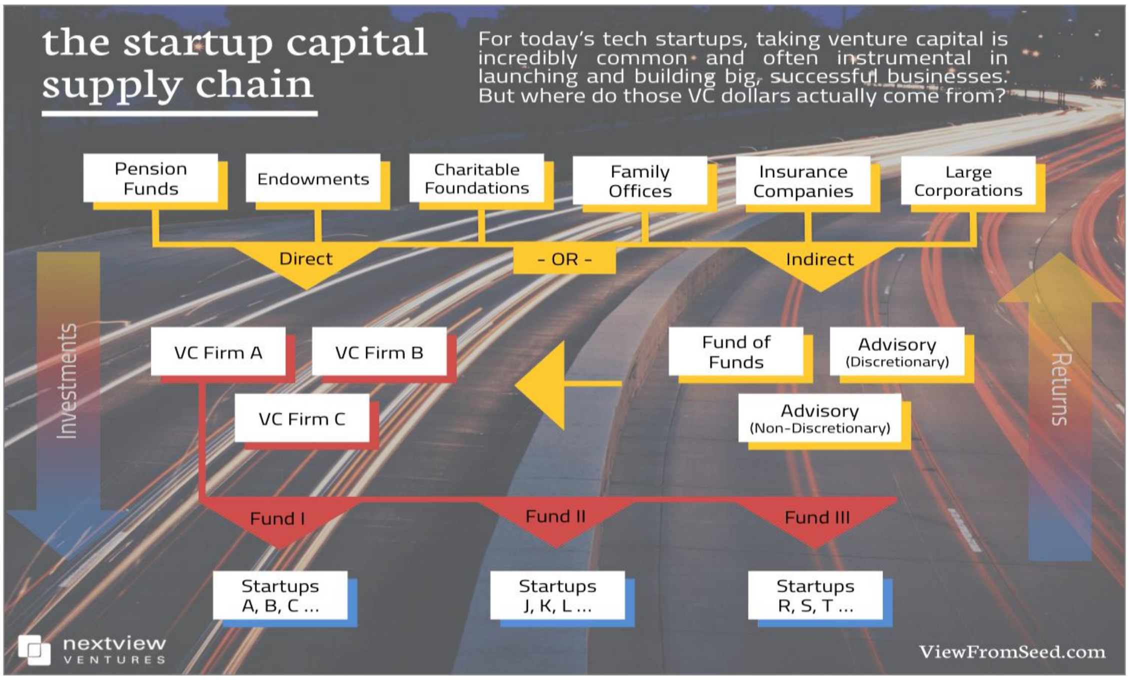
Although, VC activities have considerably and rapidly spread across the globe; Schwienbacher (2005) argues that there still exist substantial differences between the U.S. VC industry and the rest of the world particularly in areas such as - the use of convertible securities, the need for change of management upon investment and the degree of deal syndication. Nevertheless, since the advent of globalisation in the 1990s, the access OECD countries have to efficient capital markets; skilled workforce, effective intellectual property protection and sophisticated research facilities have significantly increased their VC activities (Djankov et al, 2008). According to Aizenman and Kendall (2008), the UK is regarded as one of the top net recipients of foreign VC investments because the government has endeavoured to create conducive environment that enhances VC performance. Samila and Sorenson (2009) obverse that due to the positive effects VC has on a country’s sustainable economic growth and youth employment; governments around the world are eager to create a more favourable atmosphere for VC investments in order to meet stakeholders’ expectations.

5.1.2 Structure of VC Investments

In this research report, ‘VC is defined as an independent, professionally managed, dedicated pools of capital that focus on equity or equity-related investments in privately held, high growth companies’ (Gompers and Lerner, 2001). VC firms are in the business of investing in, building up and selling off companies for a profit in order to create value for all stakeholders. The complex nature of VC investments require certain level of specialty within a longer working framework (usually 5-7 years); making it an ideal alternative investment asset class for sophisticated boutique financiers. According to Jeng and Wells (2000), VC is a type of private equity which involves equity investments made, typically in new and entrepreneurial companies, for the launch of a seed or start-up company, early stage development, or expansion of a business. Schwienbacher (2005) defines VC as an illiquid investment into high risk firms which initially do not possess positive cash flows but provide viable exit avenues from which investors maximize fund earnings.

VC funds are a collective investment scheme used in making investments in various portfolio companies. The legal structures of VC funds are usually limited liability partnerships which allow fund providers capital gains tax exemptions and diversification benefits. The legal framework consists of limited partners (i.e. suppliers of VC funds) and general partners (i.e. directors of VC firms). VC funds require partnership deeds between VC firms and VC fund Suppliers which is usually a well-structured legal agreement that includes the minimum fund size; the expected fund life; common goal; conflict resolution mechanism such as disclosure policies and review procedures; and also the compensation framework. According to Landstrom (2007), the 'three' main VC activities can be divided into: 'fundraising' from limited partners, government sponsors and fund of funds; 'investing' into the controlling shareholdings of high growth start-up companies; and exit strategies for 'divestment' and fund reallocation. The returns on VC investments are dependent on the growth and profitability of their portfolio companies. The returns are earned when VC firms sell their shareholdings to the public through initial offerings (IPOs) and/or to its industry competitors via mergers and acquisitions (M&As). While bankrupt portfolio companies are regarded as losses to the VC funds and negative goodwill to the VC firms.

Figure 5.1: Structural Diagram of VC Industry Activities



Source: http://www.agilevc.com/blog/2014/10/29/where-do-venture-capital-dollars-actually-come-from.html

5.1.3 Key Activities in the Venture Capital Industry

According to Landstrom (2007), the 'three' main VC activities are: 'fundraising' from limited partners and via fund of funds; controlling 'investments' in high growth start-up companies; and exit strategies for 'divestment' and fund reallocation. The returns on VC investments are dependent on the growth and profitability of their portfolio companies. The returns are earned when VC firms sell their shareholdings to the public through initial offerings (IPOs) and/or to its industry competitors via mergers and acquisitions (M&As). While bankrupt portfolio companies are regarded as losses to the VC funds and negative goodwill to the VC firms.

5.1.3.1 VC Fundraising

VC fundraising is basically all the activities undertaken by VC firms to attract funds from limited partners (LPs) in order to secure private equity financing for the purchase of unlisted stocks of high growth portfolio companies. Investopedia defines VC funds as 'an alternative investment asset class which seeks and manages private equity stakes in small- and medium-size start-ups' characterized by high-risk/return opportunities.

Due to the lacklustre returns from VC investments and the tight exit markets since the global financial crisis (GFC) in 2008; LPs have been reluctant and sometimes unable to provide sufficient funds to GPs. The annual sum of new financial commitments made by LPs in the U.S. from 2009 to 2014 continues to be significantly less than the annual VC deals (NVCA Yearbook, 2014). VC fundraising has been challenging and competitive in recent years; nevertheless, VC firms have outperformed other players in the private equity (PE) industry.

5.1.3.2 VC Investing – Deal Making

VC deals cover the process of screening, identifying, negotiating, announcing and managing investments in portfolio companies for the sole aim of maximizing stakeholders' value. General Partners (GPs) make financial commitment towards their portfolio companies as VC deals are reached with the young entrepreneurs at different stages of their business life cycle.

5.1.3.2.1 Stages of Financing for VC Investments

'Seed Stage Financing' is when VC investments at this initial phase in the business life cycle of the start-up companies involve the provision of a token amount of private capital for pre-marketing purposes. Young entrepreneurs receive finance to - prove a concept, test a product, further develop a computer program, carry out a market research, write up a professional business plan and/or secure a patent. 'Early Stage Financing' is when VC directors at this critical stage are concerned with funding business activities in - product marketing, industry networking, leasing contracts, regulatory formality and human resources. The aim of this sort of VC investments is to make the start-ups commercially viable.

'Expansion Stage Financing' is when VC firms provide funds to portfolio companies at this growth stage in order to - mitigate negative cash-flows, maximize highly profitable opportunities, meet new industry expectations, advertise product/service to target audience, acquire greater service licence, increase production capacity, adapt to regulatory changes and/or improve customer relations. VC directors become more strategic at this financing stage because of the maturity of the portfolio company. 'Later Stage Financing' is when VC funds at this stage are used to finance - research & development (R&D) programs, mergers and acquisitions (M&As), and also multi-regional/national ventures of the portfolio companies. The stable growth-rate and established cash-flows at this mature stage of the business life cycle of the VC backed companies make it attractive for traditional or distressed investments. Most VC directors would be devising their optimal exit strategy in order to divest and reallocate funds to young and promising enterprises.

5.1.3.3 VC Exit Strategies

Exit strategies are established avenues VC firms employ whenever divestments are deemed necessary. As VC backed companies reach maturity usually within 5-7 years, divestments become essential due to the need to ensure the liquidity of VC funds in order to - distribute returns, evaluate performance and/or reallocate entrepreneurial finance. A classic example of VC divestments is Macintosh (1997) five types of VC exits: initial public offerings, strategic acquisitions, secondary sales to other institutional investors, buybacks from management and write offs during bankruptcy. Jeng and Wells (2000) conclude that IPOs are the most useful tool of VC investments. IPOs are regarded by VC industry experts as the most profitable exit platform for portfolio companies since it provides greater access to external finance.

Nevertheless, VC directors exit more of their investments via Buy-outs due to the ease and cost of conducting trade sale. VC exits and other activities are highly dependent on the socio-economic, cultural and geo-political external environments because it determines on the - timing, volume, amount and/or viability of VC industry operations. Cochrane (2005) argues that the performances of VC investment are could be assessed whenever the portfolio companies undertake new financing, gets acquired or goes public. According to Barnes and McCarthy (2003), the performance of a VC investment can effectively be evaluated through the proceeds of the initial public offerings or trade sales. Gompers and Lerner (2001) argue that VC exits through IPOs provide greater returns than any other exit strategy.

Bankrupt portfolios are written off by VC directors usually using fire sales; and non-disclosure restrictions are sometimes placed on all parties involved. The worldwide aggregate value and number of VC backed exits were meaningfully affected by the global financial crisis in 2008/2009. Also, it is useful to note that write-offs and sale to GPs have increased during this period in relation to the other VC divestment. Black and Gilson (1998) conclude that countries with vibrant stock market rather than bank based financial system facilitate greater VC activities. Levis (2008) concludes that venture capital investments exited via an IPO are regarded as key performance indicator of the success of a VC fund. According to Cochrane (2005), the maximum-likelihood estimate technique can be employed in order to measure the performance of VC investments because it adjust for any selection bias which may arise as a result of bankrupt portfolio companies.

5.1.4 Demand for and Supply of Venture Capital

The demand for VC funds among young entrepreneurs is quite astonishing - about 10% of the total numbers of business plans submitted to VC firms are thoroughly screened and only 1% of the entrepreneurial concepts secure financing from GPs. The factors that significantly affect the demand for VC funds are – quality of the prospective management team, viability and profitability of the business plan/concept, prevailing market conditions, level of youth unemployment, cultural perceptions associated with business success or failure, minimum capital amount required; and the tax regimes at the head office region of the start-ups.

The supply of VC funds by LPs is largely due to the - track record of the VC directors, diversification benefits accrued to the VC fund supplier, regulatory burden, cost of VC capital, religious affinity, demography, liquidity considerations, legal structure, capital gains tax regime, fund size, level of private property protection, judicial independence and cultural obligation. This report would be focusing only on the supply-side of VC investments and exits. Government agencies around the world have participated in facilitating the demand for and supply of VC funds. Policy makers in various countries have adopted schemes and instituted vehicles that enhance VC activities in order to - reduce political risk, suppress youth unemployment figures, stimulate economic growth, encourage innovation and foster wealth creation amongst its citizenry.

5.1.5 VC in Developed Countries vs Emerging Economies

A large portion of the global VC industry operations can be attributed to the entrepreneurial spirit prevalent in the United States. Also, the access OECD countries have to efficient capital markets, skilled workforce, effective intellectual property protection and sophisticated research facilities enhance their VC activities and performance (Djankov et al, 2008). Das (2010) depicts with empirical evidence that emerging market economies (EMEs) such as those of the BRICS nations - aim to attract global private investments by implementing certain economic policy reforms; paying specific attention to exchange rate regimes; providing affordable education in order to improve the skills of her workforce; and also investing in new technologies so as to facilitate communication, transportation, and other infrastructural development. Eid (2006) observes that VC investments are the principal source of finance for entrepreneurship in most EMEs.

According to Ewing (2004), VC plays a vital role in building a vibrant private sector in EMEs through the channelling of funds to young entrepreneurs unable to access seed capital from banks due to their very low appetite to finance unproven business ventures and industries. VC investments are highly essential to EMEs due to: knowledge transfer through partnerships; high liquidity which facilitate sustained economic growth; employment generation and youth empowerment; and the identification and funding of winning firms and ideas. VC in the United States and Europe plays the most dominant role in global VC activities due to their superior governance and free market principles. China, on the other hand, has begun to embrace more liberal economic policies in recent years and it is no surprise their VC industry has significantly grown ever since. The VC in developed countries is primarily focused on funding Bio-tech and IT/Software firms while VC in emerging markets concentrate on finance for the manufacturing and agricultural industry.

5.1.6 The Future of Venture Capital – ‘Equity Crowdfunding’

Sullivan (2006) coined the term ‘crowdfunding’ and describes it as the newest evolutionary form of micro financing. Golic (2013) defines crowdfunding as a new and innovative platform which links investors and entrepreneurs together through the internet in order to finance business ventures and communal activities using relatively small individual commitments but from large number of volunteers. Bradley and Luong (2014) argue that crowdfunds are a type grass root finance that is unregulated and could be traced as far back as the early 1700’s.

Manchanda and Muralidharan, (2014) observes that angel investors and venture capitalists have always been considered gatekeepers of entrepreneurial finance; but crowdfunding has now brought about a global paradigm shift in start-up financing where customers as well as the general public could become owners of a private business entity with relatively low transaction costs. Dorff (2012) argues that the 'JOBS Act 2012' in the U.S. opened a new frontier in start-up financing because for the first time, small companies can sell their stocks on the internet without registering with the Security and Exchange Commission (SEC). The global growth of crowdfunding in recent times has been quite extraordinary; the United Kingdom in 2013 crowdfunded business ventures to the tune of £120 million.

5.1.7 Research Questions

The research objective for this paper is to examine the main financial and non-financial determinants of the exit performance of VC backed nanotech portfolio companies in the United Kingdom. I want to evaluate the key performance indicators that influence the exit routes of VC backed nanotech companies. I aim to study the relationships that exist between predictors of financial performance and exit outcomes of VC investments in the UK. The research questions for this study are: what are the financial and non-financial variables that significantly influence the exit performance of VC backed nanotech portfolio companies? Do divestments within the city of London perform better than the others within the UK? Does the size of the exit deal amount affect VC performance? Do cross-border VC exits outperform those of domestic VCs?

5.2 LITERATURE REVIEW

A company's financial structure is irrelevant for real investment decisions in an efficient capital market (Modigliani and Miller, 1958). However, due to market imperfections, firm investment decisions are influenced by its financial status (Cleary, 1999). Identifying financial determinants which precisely estimate the performance of a company is crucial because it provides useful and comparable information for effective decision making (Delen et al, 2013). Firm performance measurements depict the efficiency with which the management of a company utilises its assets to maximize profits (Barkham et al., 1996). The internal growth can be qualified as a key measure of company success while controlling for externalities.

5.2.1 Performance Measurement of VC Investments

The extant literature on VC research has focused on fund level analysis for a while when measuring the performance of VC activities. The discounted cash flows from VC investments have provided useful financial metrics to assess the performance of VC funds in order to compare them with similar within the alternative investment class. It is only recently that firm level analysis has been incorporated into performance measurement of VC divestments. Chenhall and Langfield-Smith (2007) argues that management accounting has provided useful internal metrics to assess the financial performance of a firm. McKelvie and Davidson (2009) further argue that the dynamic capabilities of business entities lie at the heart of their competitive advantage. Murphy, et al. (1996) concludes that accurate performance measurement helps management with an insight into understanding the possibility of a new business failing or succeeding.

5.2.1.1 Discounted Cash-flow Returns – IRR

Discounted cash flow returns provide an effective evaluation mechanism by which VC activities can be measured for their investment attractiveness. Mason and Harrison (2002) argue that the customary measure used to ascertain the performance of funds within VC industry is the internal rate of return (IRR). This performance metrics takes into account the cash-on cash returns derived VC investments in portfolio companies that have been realised or not and net of management fees (Mason, 2010).

5.2.1.2 Firm Growth – Employee or Turnover Changes

There are significant differences between a firm’s growth and its financial performance as companies that perform well may not necessarily grow and vice versa. Matsumoto et al (1995) concludes that the most important performance metric used by security analysts are growth ratios followed by valuation and profitability measures. Barkham et al. (1996) argue that the growth performance of a firm are usually measured based on their revenue stream or the human capital employed. Barkham et al. (1996) further argues that turnover is likely the most appropriate indicator of how a firm is performing among its competitors.

5.2.2 Accounting Data as Key Predictor of Firm Performance

Beaver (1966) describe financial ratios as a quotient of two numbers which have predictive capability to determine the likely performance outcome of a business venture and are derived from elements of a financial statement prepared under generally accepted accounting principles. Gallizo and Salvador (2003) argues that accounting ratios make available valuable quantitative financial information that could be employed by both analysts and researchers to assess the operations of a firm and evaluate its position within a sector over time.

Financial ratio analysis depends on the principle of proportionality which could help explain the firm performance and their size effects (Cinca et al., 2005). Accounting ratios which are derived from the financial statements of a company provide vital information to creditors and suppliers; evaluate the competitive positions of rivals; measure the financial performance of a potential target acquisition, predict future performance using historical data, and assess management efficiency for reward purposes (Delen et al., 2013). Financial reports are the main source of information for financial performance analysis which then provides top management with valuable acumen for developing effective strategies (Marginean et al., 2015).

Edmister (1972) concludes that financial ratios are very useful tools for predicting whether a small business enterprise fails or survives. Maricica and Georgeta (2012) argue that financial ratios provide early warning signals about the evolution of a company's health and potential risks. Wang and Lee (2008) observe that financial ratios have patterns; and it would be expedient to cluster those with similar features in order to produce concise evaluation criteria for a variety of performance measurements. Liang et al., (2016) conclude that the most important factors that affect bankruptcy predictions are solvency and profitability ratios as well as the board and ownership structure. Cinca et al., (2005) observes that small firms have higher probability of failure than large firms.

5.2.2.1 Profitability Ratios

Since profit making is one of the key objectives of most business entity, evaluating the performance of any firm must at some point involve looking at the returns from investment. Due to the illiquid and complex nature of VC activity, stakeholders have to wait for a significant period of time before they enjoy the rewards from sponsoring such business ventures.

Profitability ratios are a group or class of financial metrics that are employed when assessing a firm's ability to generate sufficient income so as to exceed its expenditure and create some reserves for further expansion their growth activities or distribution to shareholders for a specific period of time. These ratios are profit margin, return on capital employed, return on total assets, etc.

5.2.2.2 Solvency Ratios

The long term survival of a firm is determined by its ability to meet future debt obligations with expected future cash flows. For a company to guarantee its going-concern status; there has to be sufficient funds available to cover its long term liabilities. In order to evaluate a business venture's ability to avoid default, it is important to envisage the probability of defaulting on future debt payments. Solvency ratios are a financial metric which provides insight into a company's long term viability and stability (Lewellen, 2004).

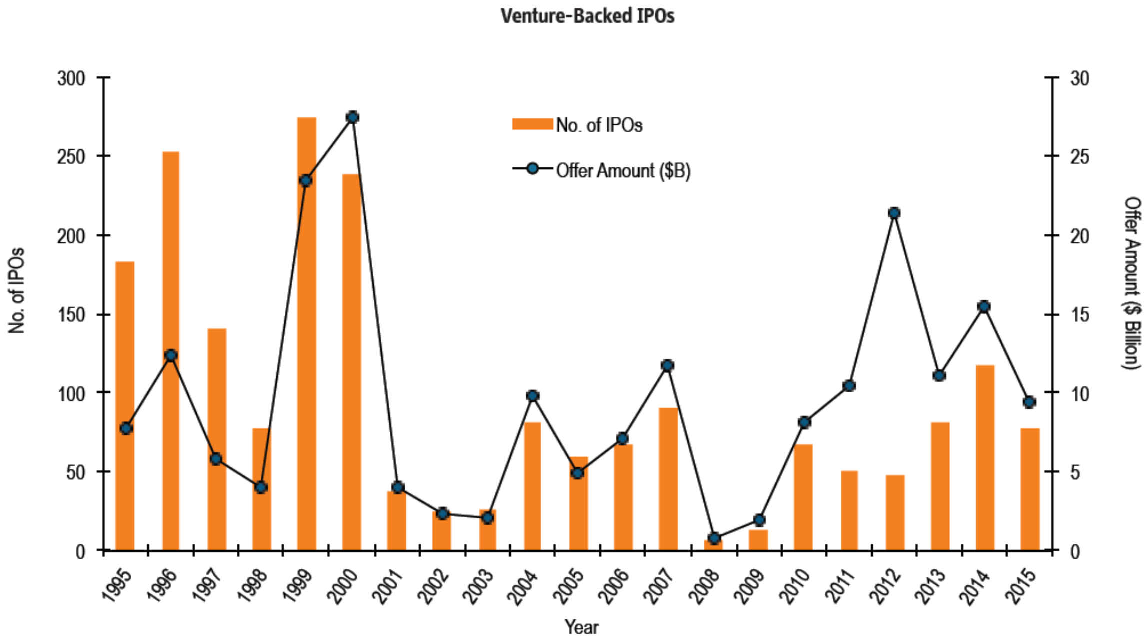
5.2.2.3 Liquidity Ratios

Working capital management is at the heart of liquidity in any business entity because it determines the funds needed for smooth day to day operations. Proper management of these funds are crucial for the survival of a firm as daily activities could be shut down due to lack of such vital cash or bank deposits. Liquidity ratios provide insights into a firm's ability to meet its short term debt obligations as they fall due. Liquidity ratios measure a company's ability to meet short term debt obligations and offer a reasonable margin of safety for their operations. These financial metrics include current ratio, quick ratio and operating cash flow ratio. A company could be solvent and illiquid at the same, causing short term crisis for financing its daily operation and then risking the possibility of bankruptcy.

5.2.3 Theories of VC Exit Performance

The performance of VC backed portfolio companies can be assessed along several dimensions. According to Zhang (2007), a successful VC funded start-up is expected to survive as a going concern, raise funds via IPOs, become very profitable in its operations and create adequate job opportunities for its stakeholders. In this research report, the numerous dimensions employed to evaluate performance are restricted to the availability of data. Wennberg and DeTienne (2014) argue that the performance of portfolio companies is a critical element that determines the possibility of a successful exit, the nature of such exit and the process in which divestments occur.

Figure 5.2: VC backed IPOs from 1995 - 2015



Source: NVCA Yearbook 2016

Baygan and Freudenberg (2007) argues that venture capital enhance their portfolio companies' performance in terms of survival rates, innovation and growth. Sahlman (1990) argues that the ability for VC firms to make a profitable exit lies at the heart of VC activities in portfolio companies. Gompers and Lerner (2001) observe that exit routes provide VC fund managers with an essential avenue for overcoming liquidity challenges; as divestments from portfolio companies are recycled into new ventures in order to facilitate the survival and growth of the VC firm. Black and Gilson (1998) conclude that exits enable VC firms to continue other activities, recover used funds, recognise unrealised profits, measure current fund performance and build a strong reputation.

Cumming and MacIntosh (2003) purports that VC will exit their investments when the projected marginal value added as a result of the VC's efforts, at any given time period, is less than the projected cost of these efforts. They further observe that the incentives for VC to exit their investments exist when there are windows of opportunity to sell into the public market or to a strategic acquirer when valuations are particularly high i.e. over-valued. Rosa et al (2003) defines VC as the pre-exit capital provided by professional investors who actively monitor the portfolio companies and argues the most preferred exit strategy of VC fund managers are the initial public offerings. Loughran and Ritter (1995) conclude that in the three years post-IPO, VC backed portfolio companies significantly underperformed a group of similar of non VC backed companies because of the unwarranted over-optimistic assessment of the long run performance by investors.

5.2.3.1 Partial & Full VC Exits

According to Cumming and MacIntosh (2003), full exit for VC backed IPOs could be defined as the sale of all equity stake in the portfolio company within one year of the deal financing completion while partial exit is the disposition of some but not all of the shareholdings within the same period. For VC backed M&As, the method of exit payment matters in determining whether there was a partial exit or not; cash payment indicates full exit while payment via stock points to partial exit. For VC exit through liquidation, write-down of book value would be considered partial exit while write-offs would be seen as full exit.

There are several factors such as the VC fund size and investment stage; the prevalent economic conditions; the reputation of the VC firm; the degree of information asymmetry amongst the parties of the exit transaction; the VC fund location and pre-exit performance; the legal and regulatory framework; etc., that influence the likelihood of a full exit during VC divestment (Arthurs and Busenitz, 2006). Bock and Schmidt (2015) observes that for VC exits via IPOs, the underwriter usually imposes a six month lockup period on the vendor to retain their investments in order to signal to new investors greater confidence in future share price thereby reduce uncertainty.

Partial exits are more likely to signal greater performance prospects to new investors as the information asymmetry increases between a vendor and an acquirer of VC Portfolio Company. There is ample empirical evidence in the literature which shows that partial ownership retention is an indicator of under-valuation of the portfolio company during VC exit (Paeglis & Veeren, 2013). The different types of exit employed by VC fund managers to divest from their portfolio companies are uniquely affected by the possibility of there been a partial exit.

Espenlaub et al., (2015) argues that the timing of exit is very significant to VC directors because the cost of further monitoring and illiquidity issues has to be weighed in against the additional value that could be introduced to the portfolio company before exit. Some of the previous studies suggest that the timing of exits are determined by several factors such as the stock market capitalisation, the quality of the legal system and other economic activities.

5.2.3.2 Cross-border VC Divestments

Schertler and Tykvova (2012) observe that the internationalisation of the VC industry in the 1990s has allowed for the vast and steady increase in cross-border VC investments around the world such that foreign VC participation in local portfolio companies now account for one third of global VC activities. Wang and Wang (2011) argue that one of the effects of globalisation has been the facilitation of cross-border VC activities due to the relative ease in labour restrictions, capital controls and banking regulations among developed countries and emerging markets.

According to Aizenman and Kendall (2012), the bulk of VC activities in the US are domestically funded but as for the UK and the rest of the world, foreign participation has been very crucial to the development of their VC industry. Black and Gilson (1998) observe that cross-border VC investments have considerably reduced the cost of the learning process for VCs as a result of the increased human capital into the domestic VC industry. Espenlaub et al., (2015) observes that cross-border VC investments are exited more quickly than domestic VC investments because of the greater marginal cost of monitoring incurred by the foreign VCs. Makela and Maula (2005) suggests that foreign VCs could provide better access to technology and/or markets for their portfolio companies than domestic VCs.

5.2.3.3 Government-sponsored VC Activities

Lerner (2002) asserts that there has been considerable government involvement in financing VC activities particularly in the funding of the operations of new high tech companies. Munari and Toschi (2015) observe that throughout Europe and around the world, various government agencies have actively develop VC initiatives which aims to mitigate the VC funding gap, leverage private VC investments and enhance the performance of technologically-driven companies. Government organisations usually justify their intervention into VC markets with the arguments that it would create employment opportunities, boost economic growth and foster successful innovative enterprises within the country.

Zarutskie (2010) purports that based on the human capital theory; government-sponsored VC firms are less likely to attract and retain talented fund managers due to low performance expectation. Luukkonen et al., (2013) argues that public VC firms are less involved in professional activities such as change of management team, identifying a suitable acquirer or recruit new board members; when compared with private VC firms. Cumming et al. (2017) observes that public VC firms lack independence in their decision making process; have weak compensation schemes; and are created by statute.

5.2.3.4 Macro-economic Factors

Gompers and Lerner (1999) argue that certain macro-economic variables (such as GDP growth, interest rates, unemployment and inflation) have a significant impact on venture capital activities. Black and Gilson (1999) support this argument with empirical evidence showing a positive relationship between GDP growth and VC investment activity. Gompers and Lerner (1999) show that a high interest rate level negatively affects VC fundraising but positively affects VC investments. Black and Gilson (1999) conclude that due to the illiquid nature of VC investments, a vibrant stock market provides the VC industry with: a crucial exit platform, a means to evaluate their performance and an instrument to facilitate the cycle of VC activities.

Beck et al., (2003) observes that VC investments in OECD countries considerably promote start-up activities which in turn facilitate job employment particularly among the youths. Berger and Udell (1998) argues that VC funds serves as an engine for economic growth due to the provision of entrepreneurial finance to new bio-tech and IT firms as well as to emerging market economies. Schertler (2003) argues that the rigidities in the labour market have a negative effect on all VC activities especially on early stage fundraising. Black and Gilson (1999) further argues that labour market regulations such as lay-off restrictions and financial compensation rules imposed in Germany and other European countries severely affect the vitality of start-ups and provides further explanation of the differences in the level of VC activities across nations. Lerner (2002) asserts that there has been considerable government involvement in financing VC activities particularly in the funding of the operations of new high tech companies.

5.2.3.5 Fiscal Factors

Poterba (1989) concludes that variations in capital gains tax rates significantly affect those VC investors with personal tax liabilities and potential entrepreneurs but exclude institutional investors like Pension funds. Auerbach and Selmrod (1997) observe that after the Tax Reform Act of 1986 was enacted, there has been considerable increase in various financial transactions that aims to avoid tax amongst very wealthy individuals. Gompers and Lerner (2004) assert that a decrease in capital gains tax significantly accelerates VC commitments at the firm, industry and country levels. Romain and Pottelsberghe (2004) assess the effects of corporate income taxation on VC investments in OECD countries from 1990 to 2000 and conclude that there exists an inverse relationship between changes corporate tax rates and VC investments.

5.2.3.6 Regulatory Restrictions

Kortum and Lerner (2001) argue that the regulatory restrictions imposed on pension fund managers with regards to investing in VC funds directly affect the supply and demand of venture capital in OECD countries. Jeng and Wells (2000) observe that the level of a country's private pension fund strongly influences VC activities in the long run. Ueda and Hirukawa (2008) further argue that certain favourable regulatory changes such as ERISA of 1979 and Bayh-Dole Act of 1980 facilitates the activities and performance of the VC industry in the United States. Krishnan et al., (2011) argues that the reinterpretation of ERISA in 1979 is generally considered as the birth of the modern VC industry due to the crucial role pension funds now play in the provision of VC funds. Timmons and Bygrave (1986) conclude that as overall VC investments increased substantially from 1979, so did initial stage financing for highly innovative start-up surge. Black and Gilson (1999) argue that the differences in the size of pension funds and the degree of regulatory restrictions to VC funding help explain the discrepancies in VC activities across countries. Also, the quality of financial reporting as evidenced by strong accounting standards seriously affects VC funding as a result of the heavy burden it places on start-up firms (Jeng and Wells, 2000).

5.2.3.7 Cultural Considerations

Hofstede (1994) defines culture as the collective programming of the mind with the objective of producing a unique value system and communal identity which distinguishes a group of people from another. Hofstede (1983) identifies four cultural dimensions which act as differentiators in order to capture the complexity of nuances that describes culture. Franke et al., (1991) observes that as VC firms become more global in their operations, the need to understand national cultures is very essential because it partly determines VC performance into their cultural environment in order to be effective in the attainment of organisational goals.

Harris (2000) argues that multinational corporations are faced with the onus of creating an organisational culture that embraces diversity in order to harness fully the skills and talents of all their employees. Basu and Yoshida (2012) assert that globalisation has facilitated the increase of trade among nations and this has resulted in the convergence of cultures and collision of linguistic practices. Based on a cross-country study which analyse cultural effects on business, Hofstede (1983) argues that the attitude of professionals could be derived from their religion and other cultural phenomenon. Licht et al., (2001) concludes that cultural variables explain the discrepancies in investor protection rights better than the legal traditions of countries and such variables as language and religion affects financial market development. Chandler and Hanks (1994) conclude that market attractiveness and resource-based capabilities influences the location and performance of VC firms.

5.2.3.8 Geographical and Other Dynamics

Beck et al (2003) argues that the geographical location and disease environment of colonies influenced the settlement strategies of European great powers which in turn affected the development of financial institutions and private property rights. Hofstede (1983) further argues that institutional fund managers are very much interested in the identity, traditions and politics of the region that their investments flow into. Gupta and Sapienza (1992) concludes that the different features of VC firms such as fund size, financing stage, management experience and ownership structure strategically determine the industry diversity and geographical location of their investments. Using dataset that encompasses countries from different world locations such as Japan, Israel, U.K., and Germany, Mayer et al. (2005) depict the geographical impact on VC investment activity where the greater the distance between venture capitalists and portfolio companies, the higher possibility of a lesser monitoring and support. There are no significant diversification benefits for VC investors with regards to location of their portfolio companies.

Romain and Pottelsberghe (2004) concludes that the rate of growth in R&D investments, the availability of knowledge stock and the size of high level patents substantially influence the VC industry in any country. More severe protection of intellectual property rights enhances the growth and performance of VC activities. According to Gompers and Lerner (1999), the level of research and development (R&D) activities within a country significantly affects its VC fundraising due to the likely increase in the demand for VC funds. Kortum and Lerner (2001) points out that the greater the VC investments, the higher the rates of patents. Using a proxy variable for the entrepreneurial culture in a given country, Romain and Pottelsberghe (2004) show that the growth rate of human knowledge influences the size of people in start-ups companies.

Kim (2008) analyse the cross-country effect of politics and stock market development and show that there exists a positive relationship between the two variables. Using data from the U.S. and Germany, Coeurderoy and Murray (2008) reveal that political uncertainty significantly affects the attractiveness of VC investments and exits. Bonini and Alkan (2009) argue that the level of corruption within a country poses a serious political risk for VC investments in all stages. Using economic geography model to study if the home market effects from individual demand on production patterns could be predicted for a set of OECD countries; they conclude that there was evidence that economic geography model could determine the production structure of OECD countries.

5.2.4 Hypotheses Formulation

- *H1: VC backed portfolio companies that have exited via living dead are less likely to be profitable than those exited via IPOs and M&As, and more likely to be profitable than those that are liquidating.*

- *H2: VC backed portfolio companies that have exited via living dead are less likely to be solvent than those exited via IPOs and M&As, and more likely to be solvent than those that are exiting via liquidation.*

- *H3: VC backed portfolio companies that have exited via living dead are less likely to be liquid than those exited via IPOs and M&As, and more likely to be profitable than those that are liquidating.*

- *H4: VC backed portfolio companies that have exited via living dead are less likely to be optimally leveraged than those exited via IPOs and M&As, and more likely to be profitable than those that are liquidating.*

- *H5: VC backed portfolio companies that have exited via living dead are less likely to be profitable than those exited via IPOs and M&As, and more likely to be profitable than those that are liquidating.*

5.3 RESEARCH METHODOLOGY

5.3.1 Data Collection

In order to assemble the dataset for the research study, I use FAME and Zephyr databases of Bureau van Dijk (BvD) to collect 1,294 VC exit outcome of nanotech portfolio companies and their corresponding book-value performance ratios from 1997 – 2016 in the UK. I extract both numerical and categorical data from Zephyr database on - the VC exit types; the total deal amount; the key sectors; whether exit is full or partial; if VC investment is domestic or foreign; Portfolio Company's age at deal year; and the total numbers of employees, directors and shareholders before and after year exit year. Using the unique BvD id numbers, I then merge the data with those from FAME which comprises of the pre and post exit performance ratios of all the VC portfolio companies.

5.3.1.1 Dependent Variables

Using a similar method adopted by Cumming (2008), in this research report, exit performance is operationalised as a qualitative dependent variable with four mutually exclusive categories. There are multi dependent variables, as the exit strategies for VC backed nanotech portfolio companies in the UK are sub-divided into four main categories namely: Mergers and Acquisitions (M&As), Initial Public Offerings (IPOs), Living Dead (i.e. young companies due exit but are unable to as their low performance) and Liquidation (Insolvency, Bankruptcy, Administration, Write-offs, etc.). There is no intrinsic ordering to the nominal dependent variables because of its qualitative features; nevertheless, the Living Dead portfolio companies are used as the base or reference group due to their high likelihood of occurrence among other categories of the response variables in the dataset.

5.3.1.2 Independent Variables

The continuous independent variables for this research study are accounting exit performance measurements that indicate the portfolio company's profitability, leverage, solvency, liquidity, employee growth, etc. I consider the average portfolio companies' book-value ratios for 24 months after the VC fund managers have partly or fully exited their investments. This provides me with the explanatory variables for the study, as I try to assess the impact of the different types of exit strategy executed by the VC firms. I capture the changes in the level of profit margins, turnover, number of employees and shareholders, size of total assets and cash-flows in order to predict the internal factors that affect the exit performance of VC investments in the UK.

5.3.1.3 Control Variables

I controlled for the amount of the exit deals, the UK location of the portfolio company, whether the VC exit was full or partial and the key sectors of operation. Dummy variables were employed to quantify the categorical variables in order to enrich my dataset when running the regressions while the natural logarithm was used to scale the exit deal amount.

5.3.1.4 Expectations of Variables

Table 5.1: Relationship of Key Variables

Variables of Interest	**Effect**
Profit Margin	+/-
Return of Capital Employed (R.O.C.E.)	+/-
Liquidity	+/-
Solvency	+/-
Gearing	+/-
Salaries/Turnover	+/-
Employee Turnover	+/-
Total Asset Growth	+/-
Full Exit	+/-
London HQ	+/-
Deal Value	+/-
Shareholders	+/-
Manufacturing Sector	+/-

Services Sector	+/-
Cash Payment	+/-
Stock (Shares) Payment	+/-
Foreign Funding	+/-
VC Financing	+/-

5.3.2 Multinomial Logistic Regression Model

Firstly, I use multiple linear regressions to study the financial factors that affect VC portfolio companies' exit performance in the UK using the average turnover growth as the dependent variable and profitability, leverage, solvency and liquidity ratios as predictors. Then, I change the response variable to the VC exit strategies of which are polytomous in nature and use the multinomial logistic regression model to create a platform from which careful consideration of the sample size is made and thorough examinations of the outlying cases are realised. The variable selection for the multinomial logistic regression is quite similar to that of the standard multiple regression.

According to Cumming et al. (2017), the multinomial logit model is the most preferred statistical tool used to differentiate the exit routes of VC backed portfolio companies. In my study, I use this model to classify the exit strategies into four groups with each explanatory variable having an individual value for each group. In order to overcome the difficulty of differentiating between the effects of several variables, collinearity is assumed to be very low as there is little use for explanatory variables to be statistically independent from each other. I also assume that the odds of VC directors choosing one exit strategy over another do not depend on the presence or absence of other irrelevant alternatives (Moske and Starkweather, 2011).

This lets the choice of K alternatives to be presented as a set of K-1 independent binary choices where VC Exits through Buy-Out is chosen as the base outcome and other K-1 exit strategies compared individually against it. My model aims to predict the probability of the different possible outcomes of the categorically distributed dependent variable given the stipulated set of predictor variables (Jain, 2001; Cumming, et al., 2017). For the nominal response variable with k categories, the model estimates k-1 logit equations. The fundamental essence of the logits is to use logarithmic function to restrict the probability values to (0.1).

5.3.2.1 *Linear Predictor Function*

The idea behind using the multinomial logit model is to build a linear predictor function that generates a score from the set of weights that are linearly combined with the independent variables of a given observation using a dot product. The score is interpreted as the utility associated with VC directors *i* choosing exit strategy *k*. The predicted outcome is usually the one with the highest score which happens to be Buy-Outs in my study. The linear predictor function estimates the probability that observation i has outcome k, of the following form:

$$f(k,i) = \beta_{0,k} + \beta_{1,k}x_{1,i} + \beta_{2,i}x_{2,i} + \cdots + \beta_{M,k}x_{M,i}$$

Where:
$\beta_{m,k}$ - is the regression coefficient associated with the *m*th explanatory variable and the *k*th outcome.
β_k - is the set of regression coefficients associated with outcome *k*.
X_i - is the set of explanatory variables associated with observation *i*.
$Y_i = K$ - is the set of response variables associated with observation *i*.

I introduce separate sets of regression coefficients, one for each possible outcome; I then derive the exponents for both sides and solve for the probabilities. Based on the fact that all *K* of the probabilities must sum to one; finally, I use the equation to find the other probabilities.

$$Pr(Y_i = 1) = \frac{e^{\beta_1 . X_i}}{1 + \sum_{k=1}^{K-1} e^{\beta_k . X_i}}$$

$$Pr(Y_i = 2) = \frac{e^{\beta_2 . X_i}}{1 + \sum_{k=1}^{K-1} e^{\beta_k . X_i}}$$

$$\ldots \ldots$$

$$Pr(Y_i = K-1) = \frac{e^{\beta_{k-1} . X_i}}{1 + \sum_{k=1}^{K-1} e^{\beta_k . X_i}}$$

5.3.2.2 *Estimating the Coefficients*

The unknown parameters in each vector β_k were jointly estimated by a slight modification of the maximum likelihood using regularization of the weights to avoid pathological results. I model the logarithm of the probability of detecting a specified output using the linear predictor along with an added normalization factor. I determine the value of Z by applying the constraint which requires all probabilities to sum to 1. The factor is constant as it is not a function of Yi which is the variable that defines the probability distribution. Nevertheless, it is certainly not constant in relation to the unknown regression coefficients β_k which is used to determine the optimization procedure.

I determine the value of Z by applying the constraint which requires all probabilities to sum to 1. The factor is constant as it is not a function of Y_i which is the variable that defines the probability distribution. Nevertheless, it is certainly not constant in relation to the unknown regression coefficients β_k which is used to determine the optimization procedure. I set the constant so that one of the vectors becomes 0, and all of the other vectors are converted into the difference between those vectors and the vector I chose. As a result, it is conventional to set $C = - \beta_k$ (or alternatively, one of the other coefficient vectors). Essentially, I set the constant so that one of the vectors becomes 0, and all of the other vectors get transformed into the difference between those vectors and the vector I chose. This is equivalent to "pivoting" around one of the K choices, and examining how much better or worse all of the other K-1 choices are, relative to the choice are pivoting around.

5.3.2.3 Estimation of Intercept

The separate odds ratios are determined for all the independent variables for each group of exit strategy with the exception of the base category which is omitted from the analysis (i.e. the Buyouts). The exponent of the beta coefficient denotes the change in the odds of the dependent variable being in a particular group in relation to the base category, associated with a one unit change of the corresponding independent variable.

5.3.2.4 Evaluating goodness of fit

Pseudo R^2 depicts the proportion of variance in the criterion that is explained by the independent variables. The likelihood ratio denotes the proportional reduction in the deviance in which the deviance is treated as a measure of variation similar but not the same as the variance in linear regression analysis. The downside of using pseudo R^2 is that it does not represent the proportionate reduction in error because the error variances vary in each value of the predicted score.

5.4 DATA ANALYSIS & FINDINGS

5.4.1 Bureau van Dijk Databases

Most of the extant empirical analysis on the performance of VC investments has been based on the evaluation of fund-level transactions using the internal rate of return as a metric for the response variable. Also, another common approach in measuring VC performance has been the assessment of the duration between receipt and exit of VC investments using survival analysis. In this study, I am limited to analysing the success of VC backed portfolio companies to only the types of exit as BvD databases does not provide adequate data on VC firms' characteristics. The amount and date of the VC and non-VC deals and their exits in the UK were collected from Zephyr database and the BvD identification numbers were used to generate historical financial and non-financial data for the portfolio companies from FAME.

5.4.2 Descriptive Statistics and Correlation Matrix

The total number of VC and non-VC backed exits and non-exits in the UK from 1997 to 2016 were 1,294 while some of the financial performance predictors are noticeably less than the total observations, it still provides sufficient framework to analyse the success of VC portfolio companies. The value of the exit deals are converted to natural logarithm to reduce the influence of outliers and provide a proxy for the size to the portfolio companies which received VC and non-VC funds. Also, the domestic or foreign affiliations of the VC funds were taken into account by considering the location of the VC firms; a dummy variable is used to indicate cross-border effects on their success. In addition, the sectors to which the portfolio companies belongs helps to identify the different industry which they operate in.

The deal payment method and planned nature of exit provide further parameters in determining the probability of a successful exit. In addition, the number of shareholders in the portfolio companies gives a proxy for the size of their corporate governance environment. *Table 5:2* below depicts the correlation coefficients between each variable and the others and is used to examine the dependence between the different variables at the same. There are both low and high correlation between some variable as expected.

Table 5.2: Descriptive Statistics and Correlation Matrix

	Variables	Mean	Std. Dev	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Profit Margin	45.2126	22.19246	1																	
2	Return of Capital Employed	4.154	9.959324	0.0679	1																
3	Liquidity Ratio	2.3333	7.44078	0.2308	-0.1065	1															
4	Solvency Ratio	1.7111	13.0212	0.0015	0.0252	-0.2623	1														
5	Gearing Ratio	16.588	44.1996	0.1462	-0.0798	0.1943	-0.3378	1													
6	Employee Turnover	8.7971	4.4124	0.01808	0.2196	0.1062	0.5013	0.2951	1												
7	Total Asset Growth	40.3325	6.3688	0.2474	0.0115	0.1166	0.1851	-0.3087	0.1718	1											
8	Salaries/Turnover	0.23214	0.8198	-0.1948	-0.1331	0.3638	0.1022	0.4221	-0.4836	-0.167	1										
9	London HQ	0.4547	0.5265	-0.0369	0.1777	0.1951	-0.1777	0.644	-0.3301	0.4723	-0.1554	1									
10	Exit Deal Value	83.5191	14.2449	0.0556	0.1022	0.4509	0.4766	-0.3088	0.2496	0.3088	0.2395	0.3449	1								
11	Manufacturing Sector	0.3333	2.9043	0.0326	-0.0846	-0.1129	0.3155	-0.2181	-0.1741	0.0474	0.0191	-0.0761	0.1087	1							
12	Services Sector	9.4402	3.2217	0.1303	0.0605	0.2441	-0.2313	-0.1052	0.0988	0.3511	-0.0081	0.1989	0.1985	0.1055	1						
13	Shareholders	0.1557	0.44813	0.1287	0.0446	0.258	0.1874	-0.058	0.0093	-0.0104	0.2478	0.0143	0.0308	0.1212	-0.2168	1					
14	Cash Payment	0.88801	1.91552	0.4301	0.0111	0.2566	-0.0215	-0.1179	0.2495	0.0665	0.0057	-0.3838	0.0474	-0.1342	-0.2002	-0.0471	1				
15	Stock Payment	15.5844	33.10245	0.1484	-0.3488	0.7898	0.1446	0.0683	0.3052	0.7039	0.0785	-0.0457	-0.1139	0.0243	0.00576	0.0098	-0.0434	1			
16	Foreign Funding	0.24744	1.115549	-0.0684	-0.0939	0.54484	-0.1774	0.0121	0.1544	0.4871	0.1515	0.5154	0.1465	-0.0864	0.4854	-0.4154	0.1166	0.144	1		
17	VC financing	0.45489	2.333449	0.0749	-0.0833	0.48777	-0.1656	0.0474	0.8774	0.4248	0.1144	0.1544	0.2144	-0.2425	0.5877	-0.1454	0.3638	0.345	0.0041	1	
18	Full Exits	0.14857	5.525848	-0.0997	0.1481	0.21545	0.4865	0.3237	-0.184	0.3526	0.1584	0.7841	0.3874	0.0147	0.4487	-0.4485	0.1951	-0.002	0.1419	0.0046	1

Table 5.2 shows the descriptive statistics and correlation matrix for this Chapter

5.4.3 Empirical Findings

The objective of this paper is to examine the financial performance predictors of VC backed portfolio companies at their exit. In order words, I evaluate the financial and non-financial determinants of the success of entrepreneurial firms that received VC or non-VC funding at their seed and growth development stage. The aim is not to assess the impact of VC and non-VC finance on their performance but rather to consider the internal factors that influence the types of exit these companies encounter at their later stage.

5.4.3.1 Multinomial Logistic Estimates

Using a multinomial logistic regression model where the response variable is categorical in nature, I evaluate the effects of performance indicators on the probability of an exit outcome of VC and non-VC backed portfolio companies; I find that the key performance metric for liquidation exits when compared with living dead non-exits is the salaries to sales ratio. This simply means that VC backed portfolio companies that exit via liquidation are more likely to lay off employees as the cost of sales per employee is high when compared with the base category. As per exits via Mergers and Acquisitions (M&A); when comparing them with the reference category, I find that M&A exits are less likely to be profitable in terms of returns on equity employed. Considering the premium paid on the target company to the VC firm for its strategic value, it is understandable. Also, I find that M&A exits are likely to experience higher growth in the shareholder numbers but surprisingly they have lower growth in their employee size. Finally, I find that M&A exits are more likely to be full exits.

VC IPO exits are more likely to be solvent (i.e. meet their financial obligations as they fall due) when compared with the base category. As the portfolio company goes public, it has greater access to funds than the reference group. Also, IPO exits - are more likely to have their head office in London; are more likely to have access to some form of foreign finance, are more likely to be in the manufacturing sector and are more likely to expand their operations. *Table 5.2* below contains the multinomial logit estimates. There are no estimates for Living-Dead non-exits as they are the base category. Model *1, 2* and *3* are similar but few variables are excluded to provide further insights for analysis.

Table 5.2: Multinomial Logistic Estimates for VC Performance

Liquidation Exit Outcome	**Model 1**	**Model 2**	**Model 3**
Profit Margin	0.0075 (-0.55)	0.00246 (-0.17)	0.00176 (-0.13)
R.O.C.E.	-0.00498 (-1.16)	-0.00495 (-1.27)	-0.00479 (-1.24)
Solvency	-0.0269 (-1.93)	-0.0279 (-1.96)	-0.0264 (-1.88)
Gearing	-0.00123 (-0.75)	-0.00168 (-1.00)	-0.00175 (-1.05)
Liquidity	0.0597 (-1.89)	0.0402 (-1.27)	0.0366 (-1.18)
Salaries/ Turnover	0.0289* (-2.24)	0.0286* (-2.32)	0.0246* (-2.1)
Total Assets Growth	0.00652 (-1.13)	0.00537 (-0.98)	0.00544 (-1.01)
Employee Turnover	-0.0112 (-0.94)	-0.00985 (-0.80)	-0.00912 (-0.77)
Deal Value	0.0532 (-0.3)	0.155 (-0.9)	0.153 (-0.89)
Shareholders	0.0215 (-0.63)	0.0128 (-0.37)	0.0113 (-0.32)
Manufacturing	-0.104 (-0.15)	-0.0174 (-0.02)	
Services	0.989 (-1.12)	0.955 (-1.13)	
Full Exits	0.999 (-1.16)	0.737 (-0.92)	0.781 (-0.98)
Cash	0.616 -0.94		
Shares	-1.529* (-2.48)		
Foreign Funding	-0.217 (-0.42)	-0.152 (-0.30)	-0.112 (-0.23)
London HQ	0.532 (-1.12)	0.446 (-0.96)	0.461 (-1)
VC Financing	0.415 (-0.77)	0.469 (-0.91)	0.454 (-0.88)
Constant	-3.775 (-1.10)	-5.643 (-1.65)	-5.481 (-1.60)

Living Dead Exit Outcomes	Base outcome		
Constant	0	0	0
M&A Exit Outcomes			
Profit Margin	0.00883 (-0.75)	0.00722 (-0.62)	0.00734 (-0.63)
R.O.C.E.	-0.00742** (-2.75)	-0.00772** (-2.79)	-0.00758** (-2.70)
Solvency ratio	-0.000973 (-0.08)	-0.000502 (-0.04)	0.0000846 (-0.01)
Gearing ratio	0.00165 (-1.39)	0.00162 (-1.37)	0.00161 (-1.38)
Liquidity ratio	-0.382* (-2.06)	-0.385* (-2.05)	-0.386* (-2.07)
Salaries/ Turnover	-0.00136 (-0.13)	0.000601 (-0.06)	-0.00177 (-0.18)
Total Assets Growth	0.00945 (-1.69)	0.00924 (-1.66)	0.00954 (-1.72)
Employee Turnover	-0.0251** (-2.58)	-0.0250* (-2.56)	-0.0252** (-2.59)
Deal Value	-0.605*** (-4.60)	-0.613*** (-4.79)	-0.620*** (-4.89)
Shareholders	0.0398 (-1.83)	0.0378 (-1.79)	0.0368 (-1.75)
Manufacturing	-0.165 (-0.38)	-0.166 (-0.39)	
Services	0.298 (-0.5)	0.225 (-0.38)	
Full Exits	-1.604*** (-4.22)	-1.560*** (-4.13)	-1.553*** (-4.14)
Cash	-0.0668 (-0.10)		
Shares	-0.435 (-1.18)		
Foreign Funding	0.0762 (-0.2)	0.0732 (-0.2)	0.076 (-0.2)
London HQ	0.647 (-1.78)	0.66 (-1.83)	0.647 (-1.82)
VC Financing	-0.283 (-0.71)	-0.264 (-0.66)	-0.279 (-0.70)
Constant	11.13*** (-4.57)	10.99*** (-4.57)	11.07*** (-4.62)
IPO Exit Outcomes			

Profit Margin	0.0167 (-1.43)	0.0183 (-1.61)	0.018 (-1.61)
R.O.C.E.	-0.00215 (-1.31)	-0.00208 (-1.26)	-0.00175 (-1.07)
Solvency	-0.0266* (-2.54)	-0.0275** (-2.66)	-0.0273** (-2.68)
Gearing	-0.00211 (-1.62)	-0.00212 (-1.63)	-0.00224 (-1.76)
Liquidity	-0.0259 (-0.42)	-0.0257 (-0.41)	-0.0236 (-0.40)
Salaries/ Turnover	-0.00173 (-0.18)	-0.00365 (-0.38)	-0.0084 (-0.95)
Total Assets Growth	0.00277 (-0.55)	0.00294 (-0.58)	0.00333 (-0.66)
Employee Turnover	-0.0165 (-1.95)	-0.0163 (-1.96)	-0.0183* (-2.22)
Deal Value	-0.656*** (-5.38)	-0.634*** (-5.42)	-0.670*** (-5.82)
Shareholders	-0.0337 (-0.36)	-0.0153 (-0.22)	-0.0171 (-0.25)
Manufacturing	-0.708* (-2.07)	-0.716* (-2.11)	
Services	-0.581 (-1.18)	-0.511 (-1.05)	
Full Exits	0.644 (-1.33)	0.628 (-1.29)	0.597 (-1.23)
Cash	0.341 (-0.57)		
Shares	0.328 (-1.020		
Foreign Funding	1.188** (-2.97)	1.212** (-3.03)	1.172** (-2.94)
London HQ	0.555 (-1.71)	0.513 (-1.6)	0.406 (-1.3)
VC Financing	0.00818 (-0.03)	0.0219 (-0.07)	0.0317 (-0.1)
Constant	10.88*** (-4.83)	10.76*** (-4.88)	11.13*** (-5.11)
Pseudo R2 AIC BIC Observations	0.221 826.5 1055 407	0.205 829.4 1033.9 407	0.197 824.5 1004.9 407

* p < 0.05, ** p < 0.01, *** p < 0.001

5.4.3.2 Endogeneity Issues and Robustness checks

The principal challenge in evaluating the determinants of VC performance emanates from the rarity of private equity data as most relevant information is not available to the general public. Specialist VC databases and country-specific data sources require huge monetary considerations and privileged associations in order to assemble useful dataset for performance analysis. It has become incumbent on VC researchers to develop robust econometric models and/or create proxies which closely represent the true parameters of interest so as to circumvent possible endogeneity problems. Performance drivers relating to value-added activities from the VC firms such as proficiency in deal syndication, networking ability, fund specialization, industry experience, and contractual obligation are difficult to measure precisely. Also, performance drivers relating to the characteristics of VC backed portfolio companies such as geographical proximity, industry growth, founder experience and firm development stage are less challenging to compute. In my research study, omitted variable biases and measurement errors constitute the bulk of the endogeneity concerns.

The complex dynamics of PE and VC investments has over the years given birth to a myriad of performance measurements. Early research studies on VC success were focused on fund-level analysis using the IRR as a metrics that depicts the discounted rate of return on VC Investment. For firm-level analysis, employee and revenue growth of VC backed portfolio companies has been used in several papers as appropriate performance metrics. In recent studies, the duration before divestment and the actual exit outcome has been used as effective measures to assess both VC fund and firm performance. These different performance measures have enabled researchers to use various econometric techniques to analyse VC data and this have given rise to some endogeneity problems. One of the key concerns in my study is whether the observed exit outcome is caused by the financial idiosyncrasy of the portfolio companies rather than the value-added performance drivers of venture capitalists (Cumming, 2008). In order to avoid omitted variable bias, I control for VC cross-border financing, experience of VCs and VC board membership; to enable me account for VC value-added performance indicators.

Also, simultaneity bias is believed to be avoided as my financial performance predictors are collected ex-ante i.e. three years before exit of the portfolio companies. Measurement error would have been present as a result of the use of historical book-value and not the true market performance metrics. I try to circumvent this by controlling for interest rate, FTSE AIM index and whether a portfolio company meets the international accounting standards (IAS). The sample selection was designed to carefully ensure proper randomisation of data collected for the research, hence, I collected both VC and matched non-VC backed portfolio companies. I performed sensitivity analyses to confirm the robustness of my results and provide evidence of structural validity for my study. In general, the results obtained through this checks are consistent with and reinforce my overall findings in this paper. The significance of my model is measured using the likelihood ratio test.

5.5 CONCLUSION

5.5.1 Limitations of the Research Study

I focus mainly on internal determinants of VC success while controlling for some external factors. The use of accounting based predictors is the major limitations of the study. Since historical costs of assets do not reflect the most recent valuation of their real values. This is a working paper and hence there are still lots of room for improvement. I intend to construct a book to market ratios for this firms and the exit timing of VC divestments using survival analysis.

5.5.2 Discussion

I study the factors that influence venture capital exit performance. My model is used to predict the probability of the different exit outcomes of the categorically distributed dependent variable given the stipulated set of performance predictor variables. I use FAME and Zephyr databases of Bureau van Dijk (BvD) to collect 1,294 VC exit strategies and the corresponding portfolio companies' book-value performance ratios from 1997 – 2016 in the UK. In order to overcome the difficulty of differentiating between the effects of several variables, collinearity is assumed to be very low as there is little use for explanatory variables to be statistically independent from each other. I also assume that the odds of VC directors choosing one exit strategy over another do not depend on the presence or absence of other irrelevant alternatives (Moske and Starkweather, 2011).

I find that M&A exits are likely to experience higher growth in the shareholder numbers but lower growth in employee size within the first 24 months of exit. Finally, I find that M&A exits are more likely to be full exits. VC IPO exits are more likely to be solvent (i.e. meet their financial obligations as they fall due) when compared with the base category. As the portfolio company goes public, it has greater access to funds than the reference group. Also, IPO exits - are more likely to have their head office in London; are more likely to have access to some form of foreign finance, are more likely to be in the manufacturing sector and are more likely to expand their operations.

The key contribution would be to provide founders of young high-tech companies and VC fund managers with useful empirical insights into factors within their control which influences the long-term continuity of their business venture with or without their active participation. My model is used to predict the probability of the different exit outcomes of the categorically distributed dependent variable given the stipulated set of performance predictor variables. I use FAME and Zephyr databases of Bureau van Dijk (BvD) to collect 1,294 VC exit types and the corresponding portfolio companies' book-value performance ratios from 1997 – 2016 in the UK.

In order to overcome the difficulty of differentiating between the effects of several variables, collinearity is assumed to be very low as there is little use for explanatory variables to be statistically independent from each other. I also assume that the odds of VC directors choosing one exit strategy over another do not depend on the presence or absence of other irrelevant alternatives (Moske and Starkweather, 2011). I find that M&A exits are likely to experience higher growth in the shareholder numbers but lower growth in employee size within the first 24 months of exit. Finally, I find that M&A exits are more likely to be full exits. VC IPO exits are more likely to be solvent (i.e. meet their financial obligations as they fall due) when compared with the base category. As the portfolio company goes public, it has greater access to funds than the reference group. Also, IPO exits - are more likely to have their head office in London; are more likely to have access to some form of foreign finance, are more likely to be in the manufacturing sector and are more likely to expand their operations.

5.5.3 Relevant Implications

The theoretical implication is that managers' of SMEs in high-tech industries could employ key internal performance indicators in determining the long-term exit firm behaviour. This could provide room for strategic alliance to strengthen internal weaknesses and exploit external opportunities in other to establish competitive advantages. Also, VC fund manager can use these accounting metrics to forecast eligibility for further funding rounds. A practical implication would be considering the financial status of a high-tech company in order to explore reasonable sources of growth funds for business expansion.

Chapter 6: Conclusion

6.1 Theoretical Contributions

A model for the relationships between the strength and duration of collaboration and the size of the partnership was proposed; which demonstrates that an effective inter-firm collaboration is dependent not only on the number of partners but also on the quality of input delivered into the nanotech R&D projects over a sustained period of time. I argue that the greater the strength and the longer the duration of R&D collaboration, the lesser the number of their partners. As the strength and duration increases, the sizes of both industrial and overall partners will most likely decrease, based on their interaction effects. I theorised that for collaborative partnerships in high-tech industries to be strong and lasting, the number of the partners must be reduced to the most optimal level. Also, I developed a model where the dimensions of collaboration among nanotech R&D organisations are affected two major forms of proximity: geographical and functional. The geographical proximity to the funding and industrial partners were categorised into different levels (local, regional, national and international) and functional proximity based on the governance mechanism and the value chain of the partners in the R&D collaboration.

Incorporating the effects of legal origin on R&D collaboration is another theoretical contribution made in this thesis. I built from the theory of law and finance initiated by La Porta et al., (1999), which stipulates that countries with English Common Law origin generally possess stronger shareholder and creditor protection than countries with French, German or Scandinavian Law origins (La Porta et al., 2008). I theorised that countries which possesses the English Common Law better protect investors against expropriations due to the effectiveness of its legal enforcement, which highlights the independence of the judiciary and reduces agency problems that result in higher dividend pay-outs (Djankov et al., 2008). Integrating the cultural dimensions in R&D collaboration is yet another theoretical contribution. I theorised that the greater the degree of society's intolerance for ambiguous and uncertain business ventures, the lower the overall partnership size, the more centralized governance mechanism, the weaker the value network and the shorter the duration of collaborative partnerships in nanotech R&D projects.

Also, I proposed that the higher the degree to which masculine values prevail in society over feminine values, the greater the partnership's size, the more centralized the governance mechanism, the shorter the duration and the weaker the value network of collaborative partnerships in nanotech R&D projects. International demand for technologically-advanced products - Higher export performance is usually associated with efficient, innovative firms that can create top-quality products at reasonably high prices for effective distribution to distant markets (Fajgelbaum, Grossman and Helpman, 2011). I theorise that the higher the export demand for a country's technologically advanced products, the greater the number of partners, the more centralized the governance mechanism, the shorter the duration and the stronger the value network of collaborative partnerships in nanotech R&D projects. The higher the rate of economic growth within a country, the greater the partner's size, the more decentralized the governance mechanism, the stronger the value network and the longer the duration of collaborative partnerships in nanotech R&D projects.

The ranking of the accomplishments in university and industry R&D collaborative partnerships for high-tech innovations is another theoretical contribution - The model was constructed from OECD's National Innovation Systems 1997 future research recommendations for measuring innovative performance of R&D projects. It depicts the phases in which new knowledge is produced and commercially secured, then further developed into innovative product/service for market consumption. The scientific productivity to technological profitability model describes the hierarchical success levels of inter-organisational R&D collaborations. The active interaction between academic scientists and industrial researchers in developing innovative products in high-tech industries is critical to building comparative advantage in knowledge-based economy. The growth of academic entrepreneurs has led to the commercialization of novel concepts derived from scientific endeavours.

Highlighting the importance of VC fund manager's participation in nanotech R&D projects is a huge contribution as VC plays a vital role in building a vibrant private sector by channelling funds to young entrepreneurs, who are unable to access seed capital from banks due to their reluctance to finance unproven business ventures and industries (Ewing, 2004). VC investments are essential to SMEs due to: knowledge transfer through partnerships; high liquidity, which facilitates sustained economic growth; employment generation and youth empowerment; and the identification and funding of winning firms and ideas. A high level of VC funding in nanotech R&D projects result in a greater innovative performance in collaborative partnership.

6.2 Managerial Implications

Nanotechnology is an interdisciplinary field that requires a great deal of physical closeness among R&D partners, who use very complex instruments to develop innovative products and services through a decentralized system of governance that minimizes contingency risks (Steinmo and Rasmussen, 2016). The results show that external factors – such as the geographical and functional proximities to key partners, a country's legal origin, cultural dimensions, economic growth rate and the level of the export demand for advanced high-tech products – meaningfully influence the partnership size and governance mechanism, strength and duration of collaboration in nanotech R&D projects. The closeness, regarding geography and functional space, of nanotech R&D firms most influences the dimensions of their R&D collaborations.

Also, nanotech firms operating in countries with French Civil Law origin are inclined to establish a centralized system of governance in their R&D collaborative partnerships, due to the high level of legal predictability. Countries with a legal origin in English Common Law are less predictable, while those with French Civil Law are less flexible (Beck et al., 2003). Legal systems which provide both a greater level of flexibility for securing patents and a higher level of predictability for estimating litigation outcomes, are likely to be more appealing to nanotech R&D project managers because there is little regulation restricting the nature and scale of research exploration and commercial exploitation or that could pose a huge threat and the possibility of large losses. However, a collaborative partnership among nanotech organizations could be employed as a market entry corporate strategy into tightly controlled industries to circumvent regulatory constraints.

In countries that seem to have a low level of uncertainty avoidance, most members of their public are more likely to be tolerant towards ambiguous or uncertain R&D ventures because of their entrepreneurial mind-set, which is at ease with risky and unstructured environments. Countries with high uncertainty avoidance index are more likely to have rigid belief systems that are intolerant of unconventional and hazardous behaviours, because the majority of the population feels anxious about unpredictable environments. A low uncertainty avoidance index evinces that members of the public are more likely to be tolerant towards ambiguous or uncertain R&D ventures. Also, a high proportion of female involvement in science and technology within a country would likely increase the strength of value networks and reduce the period of collaborative partnerships in nanotech R&D projects.

Also, I find that the innovative capacity and organizational size of nanotech firms also affect the dimensions of their R&D collaborations (Fiedler and Welpe, 2010). I argue that, because nanotech R&D projects are inherently very complex, nanotech firms that operate with a more decentralized internal organizational structure and in a simpler external environmental framework will be more effective in their R&D collaborations and hence can produce better innovative outcomes for a more abundant world. The study shows that large nanotech R&D organizations have fewer industrial partners who spend less time to develop new products, due to their strong value networks and centralized systems of governance in collaborative partnerships. Meanwhile, smaller nanotech R&D firms require more time and a greater number of industrial partners to develop new products, as a result of their willingness to impose a decentralized organizational structure in R&D collaborative partnerships.

Most large high-tech firms deliberately seek to capitalise on economic opportunities from their existing portfolio of intellectual properties in order to take advantageous position in negotiations and strengthen their bargaining chips for cross-licensing other patented technologies. The bundle of diversification benefits which a large number of partners provide in a high-tech collaborative partnership influences the scientific productivity and innovative performance in nanotech R&D projects. For instance, the existence of a financially stable and profitable high-tech firm in collaborative partnerships provides implicit guarantees and explicit endorsements that such R&D projects would likely succeed due to its accessibility to additional resources which could be deployed to ensure support and provide some valuable liquidity for R&D operations during periods of economic decline and unexpected litigation costs.

The value network of a collaborative partnership in nanotech R&D projects is strong when it is intensely incorporated vertically and horizontally from their supply-chain in order to meaningfully enhance the innovative performance of R&D projects. However, a strong value network does not necessarily mean that new products will be developed because of the complexities in nanotechnology production. A large number of foreign partners in nanotech R&D collaborative partnership provide a bundle of diversification benefits which influences the creativity and productivity in R&D projects. However, foreign alliances only facilitate the development of new products and do not significantly affects the securing of patents or the profitability of newly developed products. It means that R&D project managers or organisational strategists must focus on unique procedures which integrates each aspect of the collaborative partnership in such a way that all parties involved are required to understand and appreciate the legal and commercial external dimensions of the R&D ventures so that early profitable opportunities are identified, legal barriers are mitigated, intellectual property rights are secured and future market trends are recognised and exploited.

I find that VC funding in nanotech R&D projects usually leads to VC’s active participation in the strategic management of these collaborative partnerships, in particular to influence the size and duration of the cooperative engagements and ultimately their innovative and financial performance. The existence of VC funding in nanotech R&D projects indicates that there are significant commercial opportunities available, and that entrepreneurial prowess is prevalent in such collaborative partnerships. Also, VC fund manager can use these accounting metrics to forecast eligibility for further funding rounds. An implication would be considering the financial status of a high-tech company in order to explore reasonable sources of growth funds for business expansion. I find that M&A exits are more likely to be full exits while VC IPO exits are more likely to be solvent (i.e. meet their financial obligations as they fall due) when compared with the base category. As the portfolio company goes public, it has greater access to funds than the reference group. Also, IPO exits - are more likely to have their head office in London; are more likely to have access to some form of foreign finance, are more likely to be in the manufacturing sector and are more likely to expand their operations.

Nanotechnology will underpin the future global economy and knowledge of its commercial possibilities along with the environmental impact has to be fully explored and exploited to the highest level of its technological development (Mangematin and Walsh, 2012). The development of nanotechnology provide vast reservoir of latent innovative capacities which create business opportunities for manufacturing firms and a substantive remedial solution to the gradually hollowing-out of core competencies and existing industrial prowess in advanced countries (Ikezawa, 2013). Nanotechnology would cause the next surge in technological development which would be characterised with components of radical innovation across various fields (Maine et al. 2012). Commercial motivations is likely enhanced in nano-scientists as their research activities are applied in nature, receive huge public funding and have little regulatory barriers (Nikulainen and Palmberg, 2010). A collaborative partnership among nanotech organizations with foreign designations could be employed as a market entry corporate strategy into tightly controlled nanotech industries to circumvent regulatory constraints.

R&D project managers are required to maximize human resources in a way that circumvents the challenges and riskiness of developing new products which are safe and viable in the market place. This would require having a structural procedure in place which seeks to facilitate timely interactions among all partners in such a way that the conceptualisation of new products are harmonised at inception and strategically evaluated by top managers so that adequate resources could be channelled into the development of these new products on time. The fierce global competition in the development of nanotechnologies raises legitimate concerns whether ethics could become a casualty in the race for technical superiority. So it is incumbent of industry participants to undertake self-examination for early risk identification and avoidance of harsh regulatory measures (Linton and Walsh, 2012). The impact of nanoscience and nanotechnologies has been keenly highlighted by prominent individuals, interest groups and even in the movies, so as to promote thorough risk assessments and further regulatory activities, and ensure that a high level of ethical standards are employed during commercial development. These assurances have significantly reduced the British public’s concerns about the ambiguities in nanoscience and nanotechnology. Therefore, it is imperative for nanotech firms in countries with an English Common Law origin to take into consideration the additional cost required to make risk assessments about their R&D ventures publicly available, in order to enhance public awareness and reduce the general intolerance for uncertainties associated with nanotechnology.

6.3 Limitations

One of the main research limitations of the thesis is that scientific productivities (such as peer-to-peer publications) in inter-firm R&D collaboration were not captured. My research objective was focused on the innovation and financial performance of the nanotech R&D projects which limited the spectrum of the performance analysis of the inter-firm collaborations. The availability of data on the process innovation of nanotech companies is scarce, so in this study, only focused on the nanotech companies which have significantly engage in product innovation. Specialist database like Nanowerk are costly to access and it still has limited data on the process innovation of nanotech R&D firms.

Although, the sample size was not too small to carry the needed statistical tests However, it was however small. 30 one-one-one interviews with top executives of nanotech organisations were conducted and 97 questionnaires given to senior administrators of nanotech R&D projects across 12 European countries. To expand the sample size in the future, Skype call could be employed to reach greater number of top executive and senior administrators in nanotech R&D organisations and extract useful information for further analysis. The primary focus in high tech industry was on nanotechnology R&D organisations. Sufficient comparison between Biotech, ICT, Fintech and other high tech industries was not adequate due to the scope of the research study. Although, nanotechnology has a very high level of inter-firm partnership but it would be useful gain insight into the factors that influence the dimension of collaboration in other high-tech industries.

There are other significant variables, not included in these models, which influence the ability of nanotech companies to collaborate and successfully invent profitable products that can secure long term performance. Certain key features of a company – such as its age, size, market position, and corporate governance – could be useful tools for predicting the propensity to enter successful collaborative partnerships.

6.4 New Avenues for Research

Suggestions for future research usually come from the limitations in the research study. In the future, it would be interesting to see how the internal and external factors (used in this thesis) influence the performance of R&D collaboration which leads to process innovation in nano and other high-tech industries. The enhancement of the process of developing a high-tech product or service is much difficult to measure because it involves modifications across all the value chain activities of the R&D organisation, including improved manufacturing processes and effective media strategy.

Future research should consider observing and analysing the dimensions of inter-firm R&D collaboration across the globe, instead of only the continent of Europe, as was in this thesis. The US, for instance, has a very large number of inter-firm R&D collaborations and it would be useful to know the level of influence. The rise of young fin-tech companies which could disrupt the traditional financial institutions is a phenomenon researchers can explore; their innovation and financial performance would be interesting to analyse when compared with other high-tech industries. It would be interesting to know how other alternative finance differs from venture capital. Crowdfunding is a good example of a potential source of R&D investment for high-tech industries.

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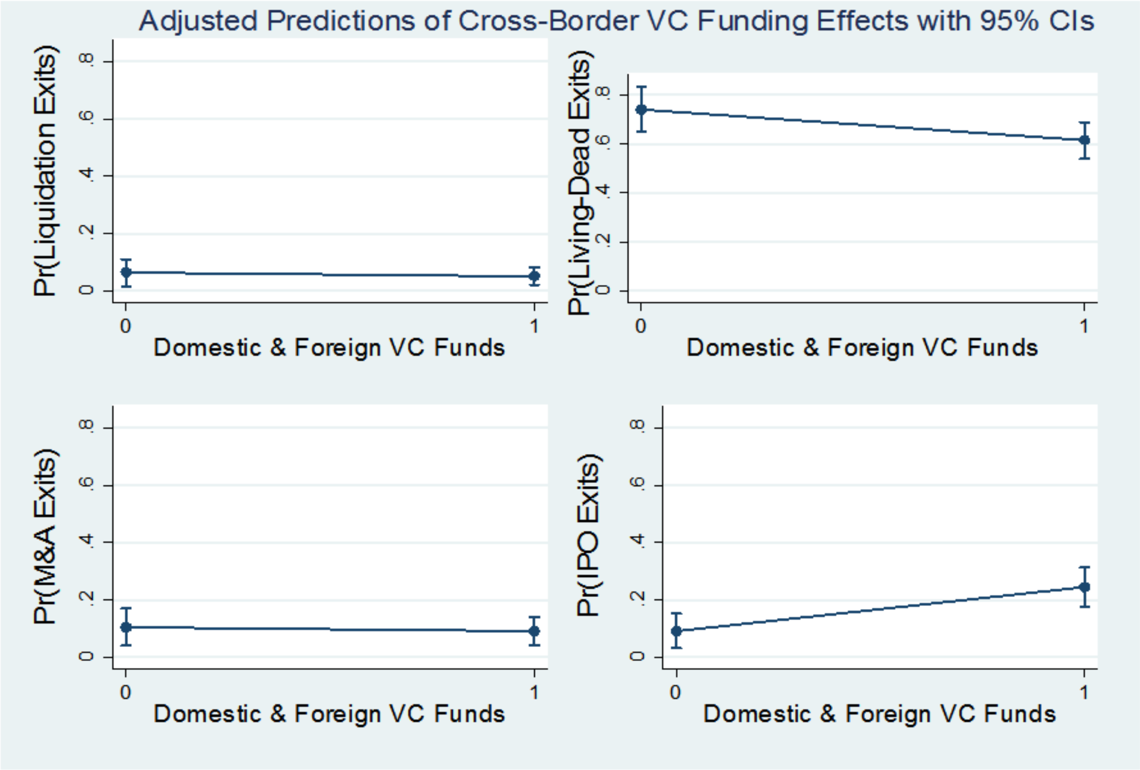
Appendices

Appendix A



Appendix B

Collaboration of SMEs

Preliminary Data Analysis Tables

2016 10 31

Sort by

(1) 3. Country,

(2) 2. Public,

(3) 5. Size

(4) 1. Name

1. Your organisation

30 unique companies

4. Name of project (Acronym)

97 unique projects

2. Type of organisation [Public (Univ. and PRI); Private]

Private	Dummy 1	43
Public	Dummy 0	54
Missing	Try BvD: IMEGO: IMU-INS	0
Total		97

3. Country

country	#	Legal origin		Religion, etc. …
Austria	2	Civil German	2	
France	5	Civil French	3	
Germany	38	Civil German	2	
Greece	2	Civil German	2	
Hungary	5	Civil German	2	
Italy	1	Civil French	3	
Netherlands	4	Civil French	3	

Slovenia	2	Civil German	2	
Spain	12	Civil French	3	
Sweden	11	Scandinavian	1	
Switzerland	2	Civil German	2	
UK	13	Common Law	0	
Total	97			

5. Size of organisation (No. of employee)

40	5	Dummy 1
>250	85	Dummy 0
<250	7	Dummy 1
Total	97	

6. Collaboration scale (national/international)

Institutional	6	Scale 1
International	42	Scale 4
National	43	Scale 3
Regional	6	Scale 2
Total	97	

7.Collaboration mechanism / type(…..)

centralized	27	Scale 1
decentralized	26	Scale 2
distributed	44	Scale 3
Total	97	

8. Total number of partners (public and private)

- **Scale 1: 1 to 4**
- **Scale 2: 5 to 9**
- **Scale 3: 10 and more**

9. Number of industrial partners (private only)

- **Scale 1: 0**
- **Scale 2: 1 to 4**
- **Scale 3: 5 and more**

8. Total number of partners (public and private)

1	10
2	12
3	8
4	6
5	12
6	5
7	6
8	6
9	7
10	2
11	1
12	2
13	2
14	2
15	1
16	1
20	1
23	1
24	1
25	3
29	1
30	1
35	1
36	2
40	1
50	1
Missing	1
Total	97

9. Number of industrial partners (private only)

0	24
1	13
2	8
3	8
4	9
5	3
6	3
7	3
8	1
9	3
10	1
12	4
13	2
18	1
19	1
20	1
21	1
25	1
40	1
Missing	9
Total	97

10. Origin of funding for the nanotech R&D projects

EU	30	Scale 1
Industry	4	Scale 3
Institutional	4	Scale 3
National	43	Scale 2
National, EU	1	Scale 1
National, EU, Industry	2	Scale 1
National, Industry	6	Scale 2
Other	3	Scale 3
Regional	4	Scale 3
Total	97	

11. Collaborative structure for nanotech R&D projects

(A) Single organisation, no partnership	12	Scale 1
(B) Horizontal value chain - you work with complementor(s)	34	Scale 3
(C) Vertical value chain -- you work with supplier(s) and customer(s)	13	Scale 2
(D) Value network -- you work with complementor(s) as well as supplier and or customer(s)	38	Scale 4
Total	97	

12. Level of collaboration with the partners

A. Strong, short term relationship	22	Scale 2
B. Strong, long term relationship	51	Scale 4
C. Weak, short term relationship	3	Scale 1
D. Weak, long term relationship	12	Scale 3
Missing	9	Missing
Total	97	

16. Main market sector(s) covered: Market 2

Aerospace/Space Science	3	Dummy 1
autarkic sensors	1	Dummy 1
Automation	1	Dummy 1
Automotive and Transport	6	Dummy 1
Biotechnology	4	Dummy 2
Construction	1	Dummy 3
Consumer Products (Electrical, Games, ...)	12	Dummy 4
Food	2	Dummy 4
Industry (equipment manufacturers, metrology equipment)	1	Dummy 1
Information and Communication	10	Dummy 5

logistic	1	Dummy 6
Medical/Surgical	7	Dummy 2
non destructive evaluation (NDE)	1	Dummy 7
Pharmaceutical	5	Dummy 2
Scientific/Academic Community	3	Dummy 8
Security	1	Dummy 5
Missing	38	Missing
Total	97	

17. Main market sector(s) covered: Market 3

Aerospace/Space Science	4	Dummy 1
Automation	1	Dummy 1
automation...	1	Dummy 1
Automotive and Transport	1	Dummy 1
Biotechnology	3	Dummy 2
cold chain	1	Dummy 9
Consumer Products (Electrical, Games, ...)	6	Dummy 4
Domestic Products (Clothing, Furnishings, ...)	1	Dummy 4
Electronics Industry	1	Dummy 4
Energy/Chemical	6	Dummy 10
Food	1	Dummy 4
Geo-surveying	1	Dummy 5
Information and Communication	4	Dummy 5
Medical/Surgical	8	Dummy 2
Metrology instrumentation	1	Dummy 2
Optics	1	Dummy 2
Missing	50	Missing
Total	91	