Commercializing Synthetic Biology: Responsible Innovation and Societal Challenges-Case Studies in the U.K., and China

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Abstract

A responsible, sustainable and ethical approach to innovation has been demanded in industries, especially in emerging technology areas such as synthetic biology (SynBio) wherein undefined potential issues exist. Responsible innovation has been promoted as a potential response among policymakers, researchers and companies. However, few frameworks of responsible innovation have been investigated on a company management level. Additionally, the scope of responsible innovation may be wider in commercial practice than in theory, including cooperation and social responsibility, for example. The nature and the technological base of synthetic biology make these frameworks less practical and more debatable at the management level, not only because the working definition of synthetic biology itself is debatable but also because the regulations of the societal aspects of synthetic biology are vague. How to implement responsible innovation in synthetic biology commercialisation is therefore still unclear.

This MPhil thesis seeks to provide a deeper understanding and investigation of the approaches that companies have applied to embed the concept of responsible innovation in synthetic biology commercialisation in the UK and China.

Qualitative methods will mainly be employed in this study. First, an overview of the synthetic biology landscapes of both countries will be presented based on the “landscape interviews”. Then, semi-structured, in-depth interviews will be conducted to gain a deep understanding of responsible innovation and its role in commercialisation of the synthetic biology industry. The data will be collected from synthetic biology companies located across the two countries: UK and PR China. These two countries have been chosen as representative of different jurisdictions, innovation systems and public mentality.

The original contribution of this thesis is that, firstly, it offers a previously under-explored perspective on responsibility activities, addressing how different innovation systems shape firms’ responsibility and top managers’ contributions to mobilising and guiding responsibility activities within industrial settings. Thus, it adds to the existing RRI literature viewing responsibility from a top-down approach, and specifically in research settings instead of industrial ones.

Secondly, the qualitative approach adopted by this study contributes a wealth of descriptive data and storytelling material regarding firms' responsibility behaviour, taking into account firms' macro external innovation ecosystem and micro internal environment. This in-depth approach also showcases the significance of training on a national level and on a firm level in the initiation and implementation of responsibility activities, which has yet to be sufficiently addressed by the literature.

Declaration

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

Copyright Statement

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**Welcome to Phoenix year one. **

1. Introduction

1.1 Motivation and research background

Emerging technologies and industries, such as synthetic biology (SynBio), artificial intelligence (AI) and advanced materials, have received great attention from policymakers, governments and industries as disruptive innovations (McKinsey Global Institute, 2016), not only for their holistic impact on a country's GDP growth (Solow, 1957), but also for sustainable responsible development of these technologies for the long-term benefit of society. A responsible, sustainable and ethical approach to innovation has been demanded in industries, especially in emerging technology areas, such as synthetic biology, wherein undefined potential issues exist. Responsible innovation has been promoted as a potential response among policymakers, researchers and companies.

There are debates about the definition and framework of responsible innovation as well as its assessment and implementation procedures. One renowned responsible innovation framework was developed for UK Research Councils, mainly at the governance level, and applies to commercialisation. However, the nature and the technological base of synthetic biology make this framework less practical and more debatable at management level, not only because the working definition of synthetic biology itself is debatable but also because the regulations of the societal aspects of synthetic biology are vague. How to implement responsible innovation in synthetic biology commercialisation is therefore still unclear. Much of the recent research has discussed how governments' innovation policies and regulations are deployed in industries to cultivate a more sustainable and responsible approach to innovation. The literature offers various angles on policies as well as how responsibility activities are conducted in individual companies. However, there is a lack of understanding of how innovation policies impact individual companies.

A commercialisation policy and innovation policy have been designed for synthetic biology in many countries, and yet there is a gap between the policy concept and commercialisation in practice (for example, that of the Technology Strategy Board UK). Understanding commercialisation and its challenges in industry facilitates the design

process of an innovation policy. Additionally, due to the complexity of synthetic biology technology, more specific commercialisation challenges are involved (for example, ethical issues). Whether the current system supports and sustains the development of synthetic biology is questionable. What is the perception in industry in terms of the commercialisation challenges that companies are facing and how can the voice be addressed by strategies or polices? These will be investigated in this research.

Responsible innovation has been a widely discussed topic recently among policymakers, researchers and companies. It is believed that innovation should not only support knowledge and economy but also human well-being (Nuffield Council on Bioethics, 2012). Therefore, a responsible, sustainable and ethical approach to innovation is essential and has been demanded, especially in emerging technology fields such as synthetic biology. How do companies perceive their responsibilities during commercialisation? What is the influence of explicit responsible innovation policies on companies?

1.2 Research abstract and chapter outline

This research investigates and compares the commercialisation and responsibility activities of the synthetic biology sectors in the UK and China. It aims to understand the de facto responsible research and innovation (RRI)/responsibility activities in the industrial sector by examining why and how SynBio companies perform responsibility activities. Additionally, it sheds light on how innovation systems differ in shaping responsibility activities in industrial settings. It addresses a gap in the literature on the perception of responsibility activities from a bottom-up perspective and a cross-nation perspective. The motivations and approaches of firms to responsibility activities and their perceptions of responsibility are investigated to answer the research questions.

This study provides an in-depth analysis of why and how firms conduct responsibility activities in the SynBio sector of the UK and China. The results indicate the significance of governments and top managers in mobilising and guiding the implementation of responsibly activities. In addition, they emphasise the significant role of training in innovation systems, both on the national level and on the firm level, in raising awareness of responsibility and facilitating implementation of responsibility activities.

Qualitative methods were mainly employed for this study. A total of 58 semi-structured interviews were conducted, including with policymakers, investors, social scientists, CEOs and CTOs of SynBio firms. The SynBio landscapes of both countries are presented based on "landscape stakeholder interviews". Semi-structured, in-depth interviews were conducted for a deeper understanding of responsible innovation and its practice in commercialisation in the synthetic biology industry. The data were collected from synthetic biology companies located across the two countries: the UK and PR China. These two countries were chosen as representative of different jurisdictions, innovation systems and public mentality. Additional data were collected through website analyses and the researcher's participation in relevant seminars organised in the UK and China.

Unlike most of the research on responsible innovation and commercialisation in the synthetic biology industry, which focuses on governance, policy or research, this thesis investigates commercialisation challenges and societal responsibilities from the company's point of view, with a combined top-down and bottom-up qualitative approach to identify the gap between current policy coverage and the demand for policy in terms of commercialisation challenges and societal responsibilities. In the UK there is a published roadmap of synthetic biology, which addresses commercialisation and responsibility. It is interesting to observe how explicit policies affect commercialisation in practice. The proposition is to explore and gain an understanding of the commercialisation challenges and social responsibilities of companies in the process of commercialisation to identify the policy coverage gap.

1.2.1 Research objectives and questions

Research objectives:

This research aims to investigate how companies perceive responsibility in this emerging technology sector, why they have such perceptions and whether the UK and China differ in their perceptions.

The main research questions are:

1. How do companies in the SynBio sector in the UK and China perceive and practise

responsibility?

2. Why do companies in the SynBio sector in the UK and China practise responsibility?

3. How do the answers to these questions differ between the two innovation systems?

1.2.2 Chapter outline

Chapter 1 - Introduction: This chapter presents the background, motivation and justification of the research as well as research objectives and research questions. It ends with a summarised dissertation chapter outline and research structure.

Chapter 2 - Literature review: This chapter navigates the academic literature relevant to this research. It starts with a discussion of the dilemmas in commercialising emerging technologies and various social aspects. It then focuses on exploring how society as a whole may become more mindful with regard to responsibility, sustainability and actability of innovating emerging technology by analysing the ongoing evolution of technology assessment tools.

Chapter 3 - Methodology: This chapter reveals the methodology used for this study, which begins with the research aim. It is followed by justifications for using a qualitative and case study method. This is followed by an explanation of the data collection method. This chapter ends with a summary of the research approach.

Chapter 4 - The SynBio landscapes of the UK and China: This chapter presents a state-of-the-art landscape of the SynBio sectors in the UK and China, establishing the context of the case studies on firms' behaviours and perceptions of responsibility and responsibility activities.

Chapter 5 - Patterns of responsibility, perceptions and behaviours of Chinese firms: This chapter provides an insight into the core motivations of Chinese firms' responsibility activities, with the focal point of the findings being on the inputs of firms' business strategies. It then elucidates how Chinese firms conduct responsibility activities, identifying

types of activities observed in the study and components that influence the implementation of responsibility activities in Chinese firms.

Chapter 6 - Patterns of responsibility, perceptions and behaviours of UK firms: This section discusses the patterns of firms' responsibility behaviours found in this study. It investigates two main questions of why and how UK firms undertake responsibility activities. It starts with the findings of how firms perceive responsibility or the frameworks of RRI in some cases. It then provides an insight into the core motivations for firms' responsibility activities, with the focal point of the findings on the inputs of top managers' personal values. The last section elucidates and analyses how UK firms conduct responsibility activities, identifying types of activities observed in the study and components that influence the implementation of responsibility activities in UK firms.

Chapter 7 - Comparison studies and discussion: This chapter provides a thorough synthetic analysis, answering the research questions by analysing firms' perceptions and behaviours through theoretical frameworks as well as comparing the patterns in each country.

Chapter 8 - Limitations and future research: For future study and to highlight the extensions and implications, this chapter identifies the research limitations, which have not yet been covered in this study, and provides recommendations where this applies.

2. Literature review

2.1 Introduction

This chapter discusses the disputes in the existing literature regarding the dilemmas that the innovation ecosystem faces when translating emerging technologies into businesses and products. The chapter starts by identifying the social aspects that may cause commercialising emerging technologies to be dilemmatic, followed by a section explaining why the synthetic biology sector is particularly dilemmatic. The section ends by summarising the social challenges with commercialising synthetic biology, leading to a discussion of how the innovation ecosystem addresses responsibility in the next chapters.

2.2 Commercialising emerging technology

Translating emerging technologies into businesses and commercialised products may cause numerous challenges, some of which are associated with the uncertain impact on human well-being and the environment. This causes dilemmas where commercialising emerging technologies, especially on a large scale, for the benefit of the human race and the environment may also create potential risks and have a social impact, which will defeat the initial purpose of commercialisation. The dilemmatic situation is a phenomenon of technologies (David, 1982) and can be caused by the lack of knowledge of the emerging technology, lack of understanding of public perceptions and the complexity of institutional functions, such as the international regulatory system. These aspects are discussed in the following section.

2.2.1 The information-power dilemma

Commercialisation of newly emerged technologies raises questions and concerns of how adequate our knowledge is to fully understand their development trajectories and the potential impact on civil society and the environment. Because the knowledge of emerging technologies evolves alongside their development, the impact of emerging technologies on human society and the environment can only be better understood as the technologies are further shaped by society in the market (David, 1982; Johnston, 2016; Liebert & Schmidt,

2010; Tannert et al., 2007). However, by then it becomes pointless to assess the impact, hard to implement control measures and expensive to make changes if the technologies develop in a way that does not benefit human well-being and the environment. Collingridge (David, 1982) argued that technology control is feasible because we should develop technologies that can be controlled (Johnston, 2016; Liebert & Schmidt, 2010). However, it is not feasible to keep every aspect of technology under control; we are living in a risky world where risks cannot be fully calculated or controlled (Beck, 2006; Beck et al., 2001; Sorensen & Christiansen, 2014). Nevertheless, with an efficient mechanism and system, risks can be predicted and kept to a minimum. The question remains of how to establish a system parallel to the development of technology and sensitive enough to detect all the potential risks.

The emergence of genetically modified (GM) food illustrates this dilemma and raises the question of how to establish an innovation system to enhance the development of technologies while being sensitive to the potential risks. Since the first wave of GM food was commercialised in the market at the mid-1990s, debates have occurred regarding the safety of this technology and its potential impact on the environment (Galizzi, 2003; Innes, 2006; Klintman, 2002; Schenkelaars, 2001; Schubert, 2002; Spence & Townsend, 2006; Stein & Rodríguez-Cerezo, 2009). There are ongoing disputes and official statements, suggesting that there is no scientific consensus on GM safety especially regarding the long-term health impact nor is there any consensus on the environmental risks of GM crops (Hilbeck, 2014; ENSSER, 2013). GM food and crops, including soybeans, maize, cotton, canola and rice, can be found widely in the market in several countries (Innes, 2006; Stein & Rodríguez-Cerezo, 2009) and most scientists believe GM food is safe for humans as there is no evidence that it could be harmful (Schubert, 2002; Chesson, 2001). Our knowledge of GM food is, however, limited, and there is a lack of scientific consensus on the risks and whether they are controllable given the wide usage of GM (Hilbeck, 2014; ENSSER, 2013). Due to the intense critical public response, some GM projects in labs were suspended permanently (Deckers, 2005; König et al., 2004), which hindered basic research breakthroughs. Despite the debates on whether scientists are right and non-scientists wrong, a mechanism in innovation ecosystem is encouraged to address the dilemmatic

situations for emerging technologies. Thus, understanding public response or public perceptions is brought into the agenda.

2.2.2 Society and innovation

To understand how and to what extent society shapes innovations along various trajectories, we must understand the perceptions of society (Teich, 2000). To understand public perceptions, it is essential to fully understand the public's engagement in shaping innovations and the public itself, also referred to as laypeople or non-experts in the literature (Wynne, 1996; Wynne, 2008; Wynne, 1992). The public plays a vital role in social shaping technology; however, the influence and engagement from the public are not always present in the ecosystem until the public are mobilised (Wynne, 2003). In contrast to what is often argued in science and society literature, the public is not always keen to get involved in decision making (Wynne, 2006). In fact, the public tends only to care about the answer to the question "What is in it for me?" after being mobilised by mass media, governments or civil society institutions such as NGOs (Scholte, 2001). For instance, a public perception survey of nanotechnology showed that the public does not necessarily have adequate knowledge of the technology, but it expresses critical concerns on the application (Burri & Bellucci, 2008), especially those concerned with daily life, the food chain or the pharmaceutical industry. Surveys also show that medical applications are associated with more positive feedback when the participants can relate the application to the real-life problems of their loved ones (Cobb & Macoubrie, 2004; Schuler, 2004; Siegrist, 2010; Siegrist, Cousin, et al., 2007; Siegrist, Keller, et al., 2007; Smiley, Smith et al., 2008; Smith et al., 2008). It is understandable that, unlike experts, (Siegrist, Keller, et al., 2007), the public cares more about real-life issues and problems. Positive feedback is often associated with 1) solving real-life problems when other methods cannot and 2) providing alternative real-life problem-solving methods that offer a greater cost-benefit ratio in comparison to other methods.

In contrast to social scientists who study public perceptions, the public is more likely to be concerned about daily life issues and ask "What is the benefit for me?", which can be seen in most surveys of public attitude towards GM and nanotechnology (Deckers, 2005; Rigby

& Burton, 2005; Cook et al., 2002; Agency, 2013; Carpenter, 2010; Sleenhoff & Osseweijer, 2013). It is worth noting that diversity in the public often complicates the question, where "benefit" may be interpreted with various meanings (Calhoun, 1993). For instance, a nanotechnology survey indicated that women expressed more critical concerns regarding food than men and the younger generation expressed more critical concerns overall than older generations (Oros, 2013; Kahan et al., 2007; Federal Institute for Risk Assessment et al., 2008). Diversity in the public raises the question of how to fully understand the public and the diversity of the public, whether it is rational for civil society organisations to represent the entire public and who exactly are the public when discussing public engagement. Nanotechnology surveys, synthetic biology surveys and the recent political events of the UK referendum and American presidential campaign prove that understanding the public is complex and may also demonstrate that understanding the public is as simple as understanding the question "What is in it for me?". When the answer is not satisfying or trustworthy, the public often expresses an indifferent or critical response.

2.3 Innovation and responsibility

2.3.1 Innovation and responsibility

Society shapes innovation at various levels (regionally, nationally, globally) and through various agents (governments, enterprises, research institutions) (Mowery & Sampat, 2005; Etzkowitz & Leydesdorff, 2000; Lundvall, 2007; Lundvall, 1992), mass media (Nordfors, 2004; Waldherr, 2012) and innovation intermediaries (Nilsson et al., 2013; Oettinger & Henton, 2013). The results of shaping technological innovation can often be seen from the trajectories of technologies where "errors" and "inefficacy", such as technology lock-ins, are not uncommon (Wilson & Tisdell, 2001; Unruh, 2000; Perkins, 2003). Because they are as numerous as the theories, technology trajectories seem difficult to predict, as does the potential social impact of technologies (Dosi, 1988, p.223). As Lundvall argued: "Two of the most salient features of innovation are uncertainty and cumulativeness" (Lundvall & Borrás, 1997). It is interesting to note that in spite of numerous arguments involving the term "society" in innovation theories, the influence of the public on shaping technology trajectories has not yet been given adequate attention in the literature. Perhaps the closest

attention can be found in technology lock-in theories, where users' increasing return to adoption and users' network externalities were argued to be two of the reasons for technology lock-in, where the influence of users can lead superior technologies to be locked out from the market, unable to compete with the preferred technology (Cowan, 1990).

2.3.2 The ongoing evolution of technology assessment

The fact that the literature fails to include the public in innovation system discussions may simply be because of the failure to recognise the power of users and perhaps to foresee the power of the non-users, given the fact that information technologies have enabled individual communications, both direct and indirect, to be much faster and more accessible (Hirsch & Silverstone, 2003). On the other hand, technology assessment tools have addressed the role of the public at an early stage, aiming at forecasting and assessing the impact of technology design and development to minimise the costs of mistakes of adopting new technologies (Schot & Rip; Brooks, 1976) and serve society (RRI Tool, 2013; European Commission, 2008). Almost all the technology assessment tools and approaches are derived from the original TA (Technology Assessment), which was initially developed in the USA in the 1960s and then institutionalised (Ely et al., 2011) around other Organisation for Economic Cooperation and Development (OECD) countries. Early TA, such as Awareness TA, focused on the dominant role of science. The evolution of TA can be seen in three dimensions: the broadening inclusiveness of players, the broadening inclusiveness of various production processes such as scientific pre-design and its implications, and the broadening inclusiveness of futurity. To elaborate, the early-stage focus on science itself has shifted into "supporting specific actors or groups of actors in formulating policies and strategies (Strategic TA)", into "broadening the decision process about technological development, to shape the course of technological development in socially desirable directions (Constructive TA)", into "shaping the development of technology through engaging multiple actors in the decision-making process to solve Collingridge's control dilemma (Interactive TA)" (Fisher et al., 2006; Collingridge, 1980, p.19), and into "emphasising at shaping future technologies to tackle grand challenges (Future-oriented TA)" (Cagnin & Keenan, 2012; Barre and Keenan, 2008; Cagnin et al., 2012). Although there

are opposing voices in the field arguing that excessive regulations hinder the advancement of innovation (Tait, 2009), responsibility does not necessarily arise through regulations.

The awareness that science should not only develop to pursue knowledge but also to improve human lives status can be traced back to as early as the 17th century (Bacon, 1962). However, it was not until the late 20th century that scientists and social scientists started to address the double-sided nature of science and its potential impact on other stakeholders and to develop the mechanisms to assess and control the risks for optimal societal benefit. Prior to that, especially in the early stages of its development, science was mostly practised for purely scientific goals regardless of the impact or potential impact it had before, during or after the work in labs. Examples of this can be seen in the development of medicine, gender research, anthropology and psychology, such as the Tuskegee Syphilis Study (1932–1972) (Resnik, 2017),[1] the case of David Reimer (1997) (Beh & Diamond, 2005), the Willowbrook State School study etc.

The increasing awareness of this essential sense of responsibility in science can be seen in the evolution of TA tools and policies where scientists collaborate with social scientists to leverage the optimal results from technologies for society. The three dimensions include the broadening inclusiveness of stakeholders, the broadening inclusiveness of various production processes such as scientific pre-design and implications, and the broadening inclusiveness of futurity.

2.3.3 RRI - what is RRI and why we may need RRI

The promotion of responsibility in science can be traced back to as early as the 17th century (Stilgoe et al., 2013). The language of natural science and social science depart into distinctive directions. Approaches by which natural scientists and social scientists could advance in parallel towards solving grand challenges overall include, but are not limited to, communicating responsibility through the innovation process and research activities. The emergence of RRI is recent with the emergence and development of New and Emerging

[1]The Tuskegee Syphilis Study, sponsored by the U.S. Department of Health. Studied the effects of untreated syphilis in 400 African American men. Researchers withheld treatment even when penicillin became widely available. Researchers did not tell the subjects that they were in an experiment. Most subjects who attended the Tuskegee clinic thought they were getting treatment for "bad blood."

Science and Technology (NEST), especially the emergence of the societal debates around nanotechnology. Political calls for responsible innovation and research are on the main discussion agenda for the EU, USA and elsewhere (Fisher and Rip, 2013).

The idea that scientists generate credible and reliable knowledge morally as a responsibility to society (Douglas, 2003) has broadened beyond scientific research (Mitcham, 2003) into the regulatory, political, environmental and social domains (Cavallaro et al., 2014; Von Schomberg, 2013; Sutcliffe, 2011; Jaap Voeten, 2012; Grunwald & Assessment, 2011).

The actual definition of RRI has been articulated by various individuals and organisations. The one that was most widely accepted by Europe (i.e. has been adopted by the European Commission) was given as an interactive process between researchers and other role players to achieve particular values as results (Schomberg, 2011). This definition was later criticised with the argument that there can be no consolidated normative between different cultures and innovation systems. Therefore, a broader definition under a macro system was promoted. The definition of Stilgoe et al. is more thorough with a different understanding of responsible innovation leading to various approaches. This will be discussed later along with responsible innovation approaches.

In this research, we adopt the latter definition with a broader vision to fit the innovation ecosystem discussion, which is as follows:

"Responsible innovation means taking care of the future through collective stewardship of science and innovation in the present." (Stilgoe et al., 2013)

Under this definition, the principles of RRI are anticipation, reflexivity, inclusion and responsiveness. (Stilgoe et al., 2013). In the case study of their research, the RRI team managed to shape the decision pathway by engaging with the research team. However, as I critiqued above, this type of engagement has no clear position on a company's strategy map so far. Companies could be very enthusiastic because it is a new responsible policy concept. How to fully engage the company from a strategic perspective and at management level needs to be explored.

This definition, with the dimensions of anticipation, reflexivity, inclusion and

responsiveness made clear, is parallel to the evolutionary trend of TA discussed in the previous section. In this study, I argue that RRI is the inevitable result of this long evolution. Current approaches concerning responsibility are mainly explored in a research environment rather than an industrial environment where commercialisation is usually prioritised given the fact that industrial organisations are profit-driven. Little is known about RRI operations in an industrial environment, especially in the balance between commercialisation and societal concerns. Although a similar dialogue engagement agenda has been promoted by social scientists in the R&D sector, reciprocal learning role clarification and (Sanden, 2012) discussion at the industrial management level is under-studied in the literature. More evidence is needed to ensure responsible innovation at both an R&D activity level and corporate strategic level.

2.4 Synthetic biology in the particular dilemmatic context

2.4.1 What is synthetic biology?

To analyse the dilemmas that synthetic biology faces, it is essential to understand what it involves. While there is as yet no agreed epistemological definition of synthetic biology, this technology is commonly perceived as a technology aimed at artificially designing, constituting and redesigning biology entities, systems or organisms that do not exist naturally (Balmer & Martin, 2008; European Commission, 2014). This emerging interdisciplinary technology is applicable in the engineering field and computing field, formulating approaches to enable the creation of "enzymes, genetic circuits, and cells" (SYNBERC, 2015) as well as biological systems in quicker, simpler and better ways (Davidson et al., 2012; Grushkin et al., 2013).

However, to further refine its working definition is challenging as synthetic biology shares blurry boundaries and overlapping technological regimes with other biological technologies, such as genomic engineering, molecular biology and genomic modifications (Cameron et al., 2014; European Commission, 2005). Additionally, the working definition of synthetic biology differs in different working areas; industry, research institutions and governments use slightly different approaches in defining synthetic biology with various focuses and purposes. It is also disputable among various schools in the same working area

(Programme & Science, 2006; Oldham et al. 2012; Nature 2014; Molecular Systems Biology 2007; Ron et al. 2006).

Despite all the debates concerning the definition, it is undeniable that synthetic biology has a close relationship with conventional biological engineering and that its aim is to make designs more workable and manufacturing more efficient (Programme & Science, 2006; Trosset & Carbonell, 2013; Church and Society Council, 2010; Benner & Sismour, 2005; Pei et al., 2011; Nature, 2014; Molecular Systems Biology, 2007; Hoffman, 2013).

In this thesis, I argue that the definition of synthetic biology should not be limited by the appearance of "standard parts". I argue that although synthetic biology and other biological disciplines may share an inclusive foundation, synthetic biology distinguishes itself by its applied-engineering approach and its designing characters. It is a new approach to biology that includes a design process of new biology units or a redesign process of existing biology systems. More specifically, it is a design and construction process of new biology units and systems or a redesign process of naturally occurring biology systems; it requires a process loop including designing, composing and testing, which only ceases when the organisms show their expected characteristics (Andrianantoandro et al., 2006; Technology Strategy Board, 2012; European Commission, 2014; Benner & Sismour, 2005). Synthetic biology should also be distinguished from the downside of existing genetic engineering technology and upside of total artificial life technology (European Commission, 2014).

Therefore, built upon the prevailing debates of what synthetic biology is and the perspectives of our interviewees, in this research we define synthetic biology as a systematic engineering of biology through gene parts to result in the targeted biological functions or organisms. The key words in this definition are design, targeted goals, applications, and engineering, which implies that synthetic biology cannot and should not be allocated only to basic research regimes. This definition of synthetic biology can be visualised using the metaphor of Lego parts, where the synthetic biology parts are represented by Lego parts. This is different from conventional biological engineering (or systems biology) parts, which can be assembled easily by the operator (History & Open,

2003). Synthetic biology aims to build up a targeted “Lego building” with specific functions using these “Lego parts”, which makes conventional genomic engineering much more systematic, faster, cheaper and gives it the ability to achieve large, industrial-scale engineering (Gibson et al., 2009; Programme & Science, 2006; Ellis et al., 2011). This definition leads to one of the key points of this research: that responsible innovation is essential in synthetic biology industry, which will be discussed further in Chapter 3. The key ingredient in synthetic biology is the engendering approach where the outcomes of biology can become more anticipatable, controllable and designable. Thus, biology is now becoming cheaper and faster.

2.4.2 Products, markets and the value chain

Reports show that the synthetic biology global market is expected to reach $38.7 billion by 2020, in which its end products will cover various areas, including chemicals, biofuels, industrial biology, agriculture, food and animals as well as pharmaceuticals, diagnostics and therapeutics. There are around 51 SynBio-applied products that have been launched on the market so far (Ellis et al., 2011), most of which are products with long-existing markets. The SynBio approach enables the production of these products to become cheaper, faster and potentially more environmentally sustainable[2]. These types of products can commonly be found in the areas of chemicals and industrial biology. There are a few potential new SynBio products that have been discussed, such as customised gene therapy in the therapeutics area, which can potentially open doors to new markets, but the question is to achieve them. Although there has been no solid evidence showing that we have fully understood the public perceptions of SynBio products in the existing markets, it is undeniable that new SynBio products may face more uncertainties. The image below demonstrates the value chain of synthetic biology where applications are categorised based on their corresponding positions (Fig. 1).

[2] Especially in comparison with the conventional chemical approach.

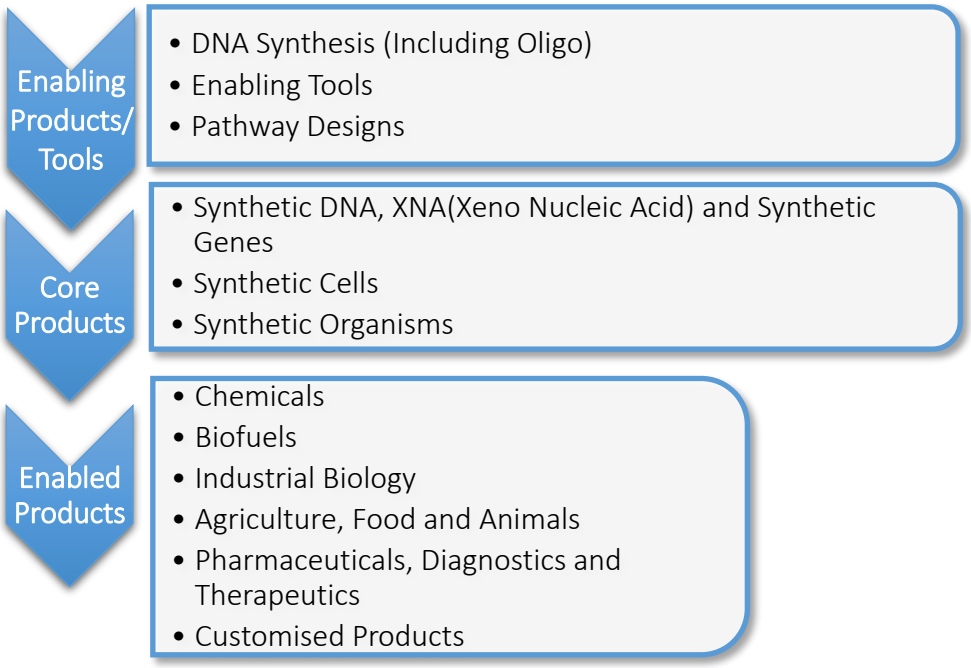

Fig. 1 SynBio value chain *(Source: Ellis et al., 2011)*

Does the name matter? The terminology of synthetic biology may or may not capture its actual technological characteristics; as argued previously, synthetic biology is a systematic engineering biology through standardised gene parts to meet the targeted biology functions or organisms—integrated by engineering, computer science, big data and biology—rather than a new biology technology, which the terminology seems to suggest (Berry, 2009). However, this may raise more bio-related phobia in public, which will be discussed in the next section.

2.4.3 History talks

GM technologies used in labs can be traced back to the 1970s, but it was not until GM food was first introduced to the market in the 1990s that there emerged numerous debates concerning GM technology and its products among politicians, NGOs, social scientists and the public (Cook et al., 2004; Schenkelaars, 2001; McHughen, 2012). The concerns of the public were mainly in two dimensions: the product dimension where safety of the application and its impact on the environment was disputed—significant scepticism was expressed especially with regard to food-related and medicine-related application—and

the authority dimension where trust of the public was driven by the attitudes towards the governments or organisations promoting the technologies.

Although there is as yet no scientific census regarding GM food safety, the expression of concerns regarding food safety concerns is neither new nor specific to GM. The phenomenon exists exciting, as in some major food safety crisis cases witnessed in Europe in the late 90s and in China in this century (Vos, 2000; Bai et al., 2007; Motarjemi, 2014; Veeck et al., 2015; Rosset, 2009; Dreyer & Renn, 2014; Lam et al., 2013; Lang, 2010; Lu & Wu, 2014), where the authority and food safety assessment mechanism was questioned and doubted. This increased the mistrust among the public towards authorities and the assessment systems. The quality crisis inevitably affected consumers' perceptions of validated food safety assessment of GMO (genetically-modified organisms) and their trust in authorities and businesses giants.

One of the most discussed industrial examples of GMO is Monsanto. The public conversations concerning Monsanto included the questions “Why is Monsanto evil?”, “Monsanto—the world’s most evil corporation”, “Is Monsanto really as bad as everyone implies?” and so on.

History matters; the mistrust among the public may reappear in the synthetic biology sector and the public will continue asking the question “What is in it for me?”. Built upon the disputes discussed previously, we categorise the challenges of synthetic biology commercialisation into the following areas:

Predicting the technology trend is not always necessarily accurate, especially the trend in relation to public perceptions. The widespread public resistance was not foreseen when GM food was first introduced to the market. Failure to communicate the benefits and engage with the public is believed to be the main reason (Wu, 2004; Gordijn & Cutter Editors, 2014). Nanotechnology is learning from this lesson and adopting a more interactive approach with the public, which can be found in NNI, STI reports and so on.

Alongside the proposed engagement agendas with the public, the concept of responsible development has been written into nanotechnology development plans. The interest of large-scale nanotechnology R&D raised unprecedented debates of ethics and social

responsibility, resulting in advocation of responsible development by the US government, which has been further conceptually developed, forming the framework of responsible research and innovation. The original goals of responsible development have also evolved into the fundamental underlying aims of responsible research and innovation.

The influence of ethical development on the nanotechnology agenda raises the question of ethical approaches of communicating innovations and maximising societal benefits. Every group of society should be considered if the underlying goal of innovation is to benefit the human race and tackle grand challenges. After all, if anything, the goal of human society lies in the expectation to achieve consensus among the majority. It has inclusively achieved the development of nanotechnology, embracing various stakeholders in the agenda and dialogues. It is worth noting that innovation that fails to benefit the majority if society may not necessarily meet the requirements for our future.

2.4.4 The challenge and the responsibility

The public perception

The public acceptance of synthetic biology is not only closely associated with the path-dependence of GM as argued in the previous section, but also with its own technology characters. Research has been done on both public understanding and acceptance of gene modifications, especially when it comes to food or anything related to the food chain (Hart Research Associates, 2014; University of Cambridge, 2014). Religion is also a challenge in terms of social acceptance (Heavey, 2013; Church and Society Council, 2010). Findings suggest that even though the public may have a low awareness of emerging technology, the majority nevertheless express their own concerns, ideas and perceptions. Qualitative research has indicated that the public is more likely to have concerns in terms of applications involving the food chain (Hart Research Associates, 2014). American data have showed that more people would accept GM plant food rather than animal food (Hallman et al. 2003). UK data have showed that most people expressed ambivalent opinions and 29% expressed negative concerns about the promotion of GM food (Poortinga and Pidgeon, 2004).

There are some concerns relating to public acceptance associated with religion as the concept of synthetic biology raises the question about whether human beings are trying to play God or are transgressing boundaries by creating new life forms. Additionally, should artificial life be treated as “natural” life, and be protected or be enabled? American statistics have indicated that religious people are more likely to express discouragement (35%–42%) while the non-religious are likely to provide more positive support (26% discouragement) (Hallman et al. 2003; Hart Research Associates, 2009).

Other elements besides religion, such as education, public mentality and innovation culture, influence public acceptance. China, one of the countries with the most non-religious population, is facing the challenge of popularising GMO products, and debates have been elevated to a political level. In 2012, a Chinese study of GM food accused an American research team of feeding Chinese children GM grain and testing the effects without informing their parents, which caused intense debates about whether the American government was using China as its GMO food test field (Charles, 2013). Although the incident was resolved with legal punishment for breaking ethical rules, the public concerns have remained and a new concern relating to the reliability of the authorities has arisen. Greenpeace (2004) generated a report indicating that Chinese customs are very resistant to GM food although some recent papers have criticised this report, arguing that their research results showed that although Chinese customs require more information on the technology, their resistance is believed to be limited. There are also reports criticising both research results and concluding that customers’ attitudes towards GM food are inconsistent with their purchasing behaviours (Huang et al. 2006; Zhang, 2002; Wang, 2003; Zhou & Tian, 2003).

The resistance from the general public is against commercialisation of new technology, which reduces the innovation value and efficiency of knowledge transformation. How companies promote their products to user groups and how companies position their user groups’ acceptance regarding this technology will be investigated as a commercialisation challenge in this research.

Biosafety and biohazards, bioterrorism and dual use

One of the main risks of commercialisation is that the products, components or materials associated with the process may become biohazards once released into the environment (Balmer & Martin, 2008; Saukshmya & Chugh, 2010; Schubert, 2007). Uncontrolled release may have an environmental contamination impact; these non-naturally existing genes may pollute the genome pool through interaction with natural organisms (Saukshmya & Chugh, 2010; Pauwels et al., 2012; Oldham et al., 2012). Not only synthetic biology, but also genetic modification technology and genetic engineering have caused the same concerns about an adventitious presence. Most of the fears about an adventitious presence occur with regard to the food chain (Schubert, 2007; Hart Research Associates, 2014). Woodrow Wilson International Centre conducted qualitative research on the public's attitudes towards synthetic biology and the findings indicated that most concerns were expressed about two applications of synthetic biology: controlling the brown rat population and creating artificial chemicals. Concerns were expressed about their potential impact on the entire food chain, especially direct risks to the human food chain (Hart Research Associates, 2014). Although this risk may be eliminated or reduced by pre-design, such as limiting organisms' survival ability by designing them to be dependent on specially sourced nutrients (Balmer & Martin, 2008), concerns still remain due to the uncertain prediction of engineered organisms' behaviour (Breithaupt, 2006). Moreover, synthesised organisms may experience more irregular behaviours because they may be constructed through theoretical script or biology "parts" filed in a synthetic biology open innovation platform (e.g. BioBricks). Therefore, more control and measurement are needed after the construction process.

From a regulation perspective, although Schubert (2007) argued that judging from history, an adventitious presence is impossible to avoid and a low level is permitted in regulations, when it comes to food, more precautions need to be taken. However, the degree to which regulatory authorities should tolerate an adventitious presence demands compliance with different jurisdictions.

Since synthetic biology is aimed at simplifying biology and enabling biology DIY, misuse is therefore much easier than with traditional biology. Potentially more deadly than

traditional bioweapons is the when synthesised organisms interact with naturally occurring ones and the latter may show an extreme reaction that causes the death of the host. An example of this was witnessed in the 1918 Spanish Flu Pandemic, where the virus has recently been proved to have been a cross between a human H1 IAV virus and an avian virus (Worobey, 2014). Although it has been argued that bioterrorism needs great attention due to the increase of terrorism around the world, biosecurity experts believe that it is hard to DIY weapons of mass destruction through synthetic biology (King's College London, 2014; Hayden, 2011; Kwok, 2010). However, pre-cautionary policies should be adequately applied because the possibility still exists (The White House, 2010; CAS, 2009; Technology Strategy Board, 2012; European Commission, 2011).

Regulatory concerns

Synthetic biology challenges patent regulations on the current patentability scope. One key argument is whether the current patent regime offers synthetic biology maximum commercialisation with minimum risk (Zhang et al., 2011). Patent regimes differ in different jurisdictions and there are therefore various problematic issues.

Firstly, whether a living form can be patented is under discussion. The US Patent Act regulates that "any new and useful process, machine, manufacture or composition of matter or any new and useful improvement thereof, may obtain a patent" (United States Code, 1952), regardless of its form. While outside of the USA, such as in Canada and Europe, securing IP for life forms is cautious (Fleising & Smart, 1993). This inconsistency of international jurisdictions initiates the phenomenon that research and its corresponding knowledge transfer will not take place in the same region, which reduces the economic benefit of the research. This also raises problematic issues for companies as to whether regional IP regimes are a barrier to commercialisation. Certainly, this limitation of jurisdiction will damage the commercialisation of local research and technology knowledge transfer. Secondly, issues related to the genetic recourses used in the lab are not covered by jurisdiction, especially not by international laws in terms of the ownership of the genetic recourses. The current approaches covering genetic recourses include state sovereign rights, free access, a common heritage of mankind, IP rights and mixed systems (Jan, 1986; Convention on Biodiversity, 2000), Different ownership approaches mean various use

purposes and use goals of genetic recourse. What approach should be adopted for synthetic biology to protect its commercialisation while preventing abuse of ownership? Thirdly, another issue associated with ethics is the ownership of IP. A registry system such as iGEM is creating an innovation exchange and sharing regime wherein concerns have been raised about whether this innovation pattern has already "damaged" the current IP regime (Chan & Sulston, 2010). Is IP within the synthetic biology industry perhaps heading towards another open innovation case, similar to the counter engineering industry? Another debate discovered during pilot work is on how to regulate the patents of bio parts to promote and sustain the development of synthetic biology.

Economic patterns

Recent investigations of consulting companies and government reports have indicated that synthetic biology has a promising commercialising potential. Its main applications in medicines and pharmaceuticals, environmental products, energy products, materials and diagnostic tool application (Technology Strategy Board, 2012; Rouilly, 2008; Zhang et al., 2011; European Commission, 2005) has a potential economic impact on roughly 26 million people and £7.2 billion market (McKinsey Global Institute, 2013; Rouilly, 2008). This economic potential highlights the capabilities of synthetic biology applications in terms of solving global problems such as shortage of natural resources and increasing demand for environmentally friendly and sustainable goods (Pauwels et al., 2012). A technical note is that these applications can be categorised and sub-divided into groups based on their technology pathways and approaches wherein the approaches are instinctively characterised by the host systems (European Commission, 2005). Thus, companies and their products can be categorised based on the biological pathways, which will be adopted when sampling companies for this research.

According to Henkel and Maurer (Henkel & Maurer, 2007) the economic pattern of synthetic biology is similar to that of the computer engineering industry, where standard biological parts are like computer codes being used by companies to programme biological systems and organisms. They argued that this economic pattern relies on the use and reuse of parts and that commercialisation is affected by the innovation network effect. Keaslin (2007) and Ro et al. (2006) mentioned that agencies would, therefore, appear in this

economic pattern and they discussed a current successful agency: Amyris Biotechnology. However, whether this economic pattern becomes the dominant pattern and succeeds will need further examination. This economic pattern is largely dependent on the future working definition of synthetic biology and whether “parts” are the basic components.

3. Methodology and data collection

3.1 Research methodology

3.1.1 Qualitative research

Various research methods have frequently been used in academic research, among which the quantitative approach provides an accurate perspective, and the qualitative approach gives a wider exploration of views of an individual that may not be possible with a quantitative approach (Hoinville, 1978). The research method should be appropriate to the research objectives and research questions (Jancowicz, 1991). This research aims to grasp the state of SynBio commercialisation in the UK and China and perceptions of responsibility in the industry and therefore, detailed descriptive information is required to provide a fuller picture and richer historical roots in order to obtain relatively accurate results. Compared to quantitative research, a qualitative research approach can examine and explore a topic more deeply especially when it is related to social interactions (Johnson & Christensen, 2008; Lichtman, 2006).

The choice of conducting qualitative research additionally stemmed from the exploratory nature of this study, which aims to investigate a dynamic and emerging phenomenon. The research on the topic of responsible innovation has merely investigated the perspectives from industry, rather it has mostly focused on the perspectives of governments and research institutions. In comparison to quantitative research where predicated factors are measured and analyzed, a qualitative approach allows storytelling in the context and in-depth insights on the topics that are not well understood.

Moreover, this research aims to investigate firms' perceptions of responsibility and behaviors of responsibility activities. A qualitative approach enables exploration of processes and patterns which cannot be easily measured. Specifically, a qualitative approach provides descriptions of patterns from which a deep understanding of firms' perceptions and behaviors can be achieved.

A qualitative approach is more valuable to explain firms' behaviors in their specific

industrial settings. It allows the researcher to gain insights into what is unknown and to discover the actual process and events “that led to specific outcomes(R)” and more importantly to answer “how and why processes, events, and outcomes occur“. In this research, particularly, the underlying motives of firms’ responsibility activities can be understood in the context of specific innovation systems and their responsibility activities can be analyzed.

3.1.2 Case study

In this study, to compare the two countries’ state of the art, a case study method was chosen as the research strategy, which provided an in-depth examination of events, phenomena, and other observations in a real-life context (Abercrombie, Hill, & Turner, 1984). Additionally, a case study enables a deep understanding of the context and its relevant process (Flyvbjerg, 2011), the significance of which is addressed by Yin (Yin, 2003).

In his work (Yin, 2003), Yin gave clear instructions on how to collect data for the case study method, where he suggested that one should obtain multiple sources of data to keep this method reliable. Therefore, the data of the case study in this research are not limited to primary data, but include multiple data sources, including company reports, industrial reports, company web content and other published documents.

3.2 Research design

As this research aims at gaining a deep understating of the commercialisation challenges in the synthetic biology industry and bridging the gap between policy concept and commercialisation, a qualitative methodology was employed throughout, mainly including the data collected by in-depth interviews.

Data was collected from SynBio companies located across two countries: the UK and PR China. These two countries were chosen not only for an interesting comparison of the different jurisdictions and innovation systems, but also for a comparison between a framework-established country and a non-established country.

The research is presented in case studies as this method provides an in-depth insight into comparative investigations (Abercrombie, Hill, & Turner, 1984) and allows extra detailed information for the research database (Yin, 2003). A case study database was established for further analysis and future studies.

There are two main frameworks adopted in this research. Richard's 4 dimensions of RRI is adopted to analyse companies' perceptions and activities of responsibility. Companies' responsibility activities were coded into two groups. This layer divides firms' activities into "embedded activities" and "side activities", emphasising the relationship between responsibility activities and their main business activities. "Side activities" represent those responsibility activities that do not impact on firms' main business, and therefore do not contain any elements from the first layer of coding.

External and internal factors are considered in order to answer research question two. Firms' motivations were coded into these two main groups-external input (including iGEM) and internal input.

Lastly, the mediating role of the CEO emerged during data analysis when comparing the findings of both companies, which is discussed in chapter 7.

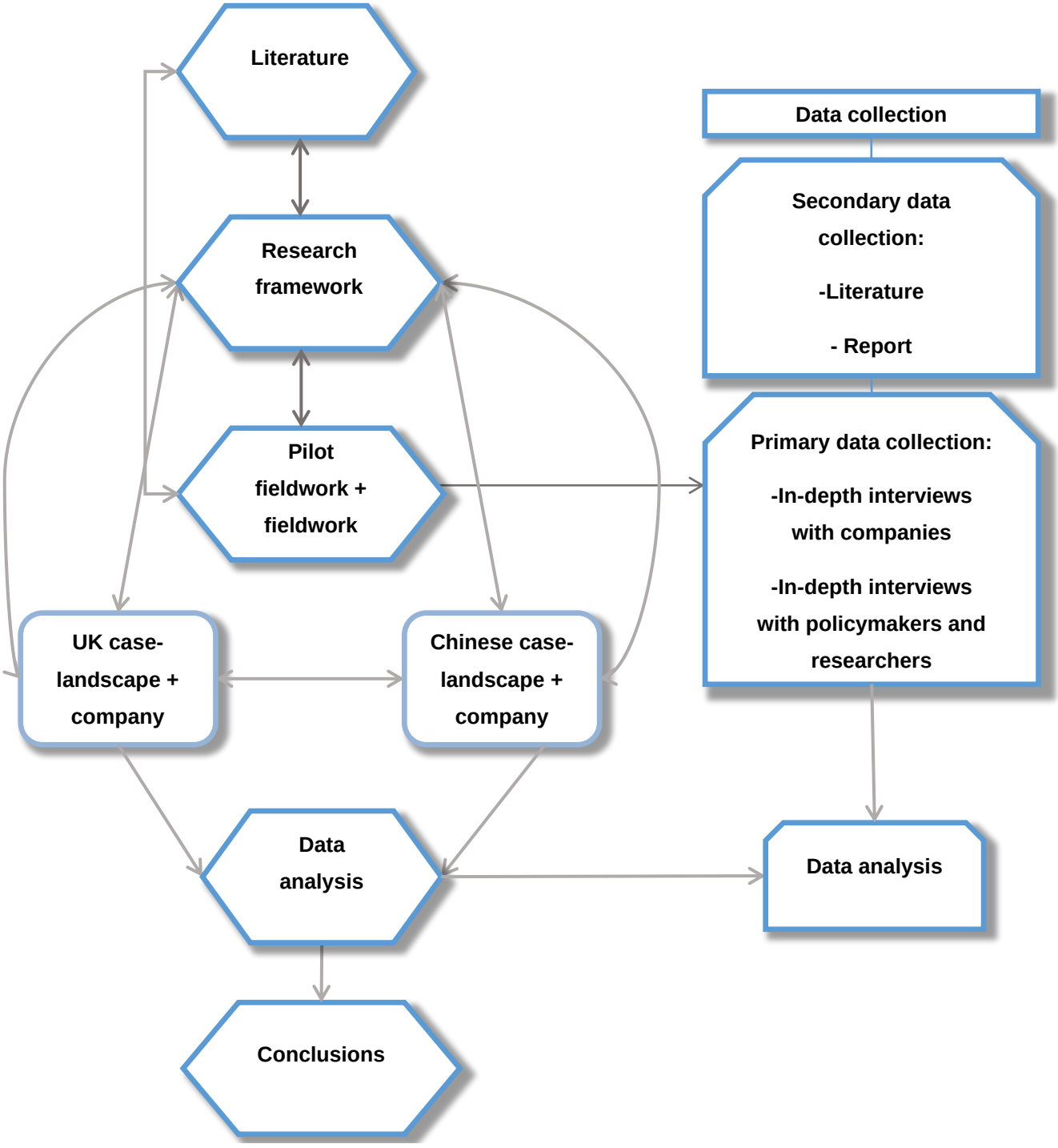

Fig. 2 Research design *(Source: Author)*

3.3 Data collection

To gain empirical evidence and conduct an in-depth examination, both secondary data and primary data are used. Secondary data was collected in order to enhance the validity and reliability of the data. Various data sources -firms' websites, research institutions' websites, industrial reports and government documents were selected in order to complement the data collected by in-depth interviews with firms, researchers and policymakers, providing extra features of SynBio landscapes and firms' perspectives and actions. All the available secondary materials of selected companies were screened, and secondary data was hand-picked and secreted until it adds no further contribution to the primary data. Therefore, relevant content of interviewed firms' websites, firms' published reports as well as other documents published by interviewed institutions and both governments were analysed in addition to interview data. The table below shows the detailed data collection methodology (Table 1).

Data collection methodology	Data sources	Description (area of investigation)
Primary research	In-depth interview	-China landscape and UK landscape -China company cases and UK company cases
	Company websites and company social media channels * (company information)	
	Academic materials	
Secondary research	Online database	-Multiple sources for case studies -Literature review
	Industrial reports	
	Others	

Table 1. Data sources *(Source: Author)*

3.3.1 The interview approach

The semi-structured face-to-face interview was adopted to collect specific and clarified information, which allows for in-depth analysis of themes that cannot be otherwise captured sufficiently (Arksey & Knight, 1999). A semi-structured protocol was developed, in which the general topics of the questions were determined, yet the sequence and the wording of the specified questions were determined later on based on the discussion context with the interviewees. This open-ended approach enables flexibility during the interview to gather rich data in which interviewees express their perspectives and opinions thoroughly (Denscombe, 1998, p.113).

To obtain accurate and less biased information thereby enhancing reliability and validity of the data set, additional approaches -"avoiding asking leading questions; taking notes not just depending on tape recorders; conducting a pilot interview; giving the interviewee a chance to sum up and clarify the points they have made and compensating interviewing with associated observations" (Creswell, 2009, p.153) were adopted during interviews. Keywords such as "RRI" and "four dimensions of RRI" were not deliberately mentioned by the interviewer during the conversations. They were, instead, only mentioned and further investigated when discussed by the interviewees.

All interviews were taken on the premises where interviewees worked apart from a few carried out on the phone. The interviews usually lasted from thirty minutes to one hour and half depending on the conversation flows, questions were asked until no further information can contribute to answering the research questions. The interview normally began with a pitch of the research topic and research aims, then the conversation opened up with a request to introduce firms' business and interviewees' roles in the firms, which creates space for interviewees to warm up and break the ice. Then the first predetermined question was asked according to the interview protocol; followed by the second question based on the answers. The interview structure and flow was mainly controlled by the researcher, in accordance with the interview protocol. All the interviews were recorded, then labeled with key words, manually transcribed and then codified.

An interview consent form together with an information sheet were additionally provided to participants to illustrate the purpose of the study as well as to gain additional informed consent. Assumed names are used where necessary. All transcriptions are confidential and will not be used for any other research or studies.

3.3.2 Case selection and informant selection

Two countries, the UK and China, where cases were selected from, were chosen as representative of different jurisdictions, innovation systems and public mentality. The company sample set was determined by a mixture approach. Online text mining of their business ranges was conducted based on their business ranges, where companies whose business ranges were within or overlapped with the synthetic biology working definition in this research were on the interview shortlist. Then they were all contacted and approached either through emails or through face-to-face conversations. The final sample was selected, amongst these that were available, with various external factors -company size, product domain (design, build or test), business nature (B2B or B2C)-taken into account. Hence, the case sample is feasible, comparative and representative. Regarding case number, cases were selected until these did not produce any further discovery (Denscombe, 1998; Creswell, 2007) and until there was sufficient confidence that the data could answer the research questions. The total number of SynBio firms were very limited due to the fact that

it was an emerging sector, therefore, the total number of case was not challenging to be determined.

The choices of informants stemmed from the needs of this research for in-depth insights on SynBio firms' perspectives of responsibility and their responsibility activities. There were two main groups of informants -managers and researchers.

SynBio researchers and policymakers, including those who work at universities and research institutions, were selected as they can provide the most in-depth perspectives of SynBio landscapes. Managers, including executive managers and managers at top management were chosen as informants as they can provide the most in-depth perspectives of firms' perspectives at a strategic and operational level. Mostly executive managers were approached and selected; managers at top management were only selected when the executives were not available. The data collected through interviews with managers were analysed to explore and understand firms' perceptions of responsibility and responsibility activities.

Semi-structured interviews were recorded and then transcribed exactly noting the conversations. The transcribed reports were sent back to the interviewees through emails for validity check. However, few replies were received; this is probably due to the fact executive managers and researchers were tightly scheduled.

3.4 Data analysis, coding and frameworks

Template analysis is conducted in this research. Template analysis encourages flexibility in coding, which allows the analyst to establish themes where rich data is used (King, 2012) Template analysis also encourages a mixture of primary data and secondary data, though the main data involved are usually interview transcripts.

In order to develop a robust template, two rounds of pre-coding analysis were conducted. A trial of template analysis was carried out through the data collected by the first round of data collection. The template was then revisited, justified and verified, alongside with the interview questions.

A preparation of coding was conducted, to familiarize with the raw data (King, 2012) by reading through the full set of data.

Then the initial template was formed through preliminary coding of the data, which was conducted through a small account of data by highlighting patterns and notions that "potentially contribute to the understanding of the research question (King, 2012, p6)." The template was then applied to the full data set and "to be modified if necessary (King, 2012, p7).

The initial template in this thesis mainly consists of two sections:responsibility perception analysis and responsibility activities analysis.

Responsibility perception analysis, which analyses firms' perceptions and opinions towards responsibility and its activities, consists of two layers of coding. The first layer is top managers' attitudes towards responsibility and its activities:"in favor","not in favor/sceptical" and "indifferent or neutral". A further layer of coding was then added under the "in favor" category in order to explore motives of firms' perceptions, in order to understand the role of specific innovation policies in forming various perceptions of responsibility. The second layer of code includes "internal input" and "external input",which provides a deep understanding of why firms take part of responsible innovation. Sub-coding groups such as "iGEM competition", "overseas experience" and "personal value" were added in order to understand the specific features of motivations. The analysis is located at section 6.2.

Responsibility activity analysis, which identifies the formation and configuration of firms' activities, consists of two layers of coding. The first coding layer identifies and indicates the type of firms' responsibility activities, "embedded activities" and "side activities", of which the codes were established based on Richard's four dimensions' RRI framework. The second layer further analyses the features of embedded activities. The external and internal factors were analysed in order to further investigate the motives of firms' responsibility activities. The analysis is located at section 6.3.

At last, the third theme emerged during the data analysis, which is the mediating role of

managers at top management. This analysis is located at section 7.4.

4. The SynBio landscapes of the UK and China

The following chapter presents the state-of-the-art landscape of the SynBio sector in the UK and China, revealing the context of the upcoming case studies on firms' behaviours and perceptions of responsibility and responsibility activities.

As discussed in the methodology chapter that this research is context-dependent and context-sensitive, the landscapes, therefore, provide a thorough foundation for the case studies, enabling a profound comprehension of firms' motivations and perceptions on responsibility and its practice. The chapter consists of two sections with each giving a descriptive analysis of SynBio sector innovation systems in both countries. Data were obtained through archives of government and regulatory documents as well as interviews with policymakers, social scientists, investors and other key stakeholders in the ecosystems of the SynBio sector in the UK and China (See Chapter 3).

4.1 Chinese SynBio landscape

Following the SynBio roadmaps published in the UK and USA, the Chinese government identified SynBio as one of the key technologies to develop for its medium- and long-term science and technology strategies. As China endeavours to achieve a global leading position in this emerging technology, providing a sound innovation ecosystem for the sector has become a key challenge for the country. The country has developed an S&T system in trying to leverage national R&D and its associated economics benefits. However, there are concerns about how China can effectively reach this leading position, which centres around its research ethics, the efficiency of the IP system and societal responsibility of associated technological developments.

The Chinese landscape section aims to reveal the latest picture of the system of Chinese SynBio firms, thereby setting the background of firms' responsibility behaviours. It provides insights into China's SynBio research, SynBio social research, relevant policies and other societal aspects.

4.1.1 The emergence of the SynBio sector in China

Being a major manufacturing country, China is urgently pursuing a transition into an innovative and intensive growth model (MOST, 2003). To facilitate this ambitious transition, the Chinese government has identified several key advanced technologies, including synthetic biology (CAS, 2011), to achieve "China Innovation 2020" and "Made in China 2050".

As early as 2006, "development and reproductive biology" and "genetically modified new-organism variety breeding" were identified as frontier technology and science mega-project respectively in China's 15-year Technology and Science Plan (Central Committee of the Communist Party of China, 2016). However, it was not until 2008 when the 322 Xiangshan Synthetic Biology Meeting was held in Beijing, that the Chinese government officially recognised synthetic biology in its S&T strategic position (XSSC, 2008). Since then, the government has been investing in the SynBio sector, especially in its basic science research area, under the leadership of the Chinese Academy of Sciences (CAS) and the Ministry of Science and Technology (MoST).

In 2009, the first Chinese SynBio lab—Key Laboratory of Synthetic Biology (KLSynB) (Shanghai)—was successfully launched under the governance of CAS, aiming for a global leading position in the SynBio sector (SIBS, 2017). Later, with the 12th five-year plan addressing SynBio as a key research area to invest in and develop on a national scale (MoST, 2011), two pioneer "973" research projects were launched. The emphasis since then has been on research regimes, with two additional "973" or "863" research projects launched every other year, and a total annual investment of over RMB 260 million laid out (Central Committee of the Communist Party of China, 2016). Ten "973" and two "863" projects have been successfully launched within the proposal of the Xiangshan Meeting, resulting in over 400 research papers published every year (CCPS, 2015; Chen & Wang, 2015).

A Chinese SynBio system was officially established with the launching of China's first SynBio Association in 2017 by CAS and Shenzhen Institute of Advanced Technology. It aims to facilitate communication and knowledge exchange in the SynBio community, both domestic and foreign, particularly communication between research institutions,

governments as well as industry, furthering the development of Chinese SynBio research at a national level (CAS, 2017).

More recently (November 2018), the Chinese government has reinforced the importance of SynBio—identifying it as one of the "three key disruptive technologies" and established a formal call for S&T research programmes with total funding of over £8.3 billion, which is almost double that of the other two identified key disruptive technologies. The SynBio S&T research programmes will be co-funded by Chinese MoST and the Shenzhen City government, given that Shenzhen has played and will play a vital role in the development of SynBio research and commercialisation (MoST, 2018).

The emphasis on SynBio technology translation and commercialisation initiatively emerged in 2010, when *China manufacturing 2050 - A road map for key advanced technologies* devised a commercialisation plan for scaling up the SynBio sector (CAS, 2010). Later, China specified its national objectives in cultivating and establishing a consummate innovation ecosystem and activated a community for the biotechnology sector, as well as the main innovative firms in this sector to pursue the global influence of Chinese innovation. The ambitions of the government in this field on paper is evident: SynBio, along with other frontier technologies and megaprojects, is leveraged by the government to pursue the global influence of Chinese innovation—changing its position from a manufacturing country to an innovative country (Central Committee of the Communist Party of China, 2006; Cao et al., 2006).

The Chinese SynBio commercialisation campaign has been recently upgraded with a newly established committee (November 2018) (Changsha) under the guidance of the Chinese Society of Biotechnology (CSBT). The committee aims to forward the basic research and application of the country's synthetic biology and explore its development direction in areas such as pathway optimising, as well as discipline construction, with particular goals of promoting indigenous SynBio research and innovation as well as efficient technological translation. The detailed strategies for leveraging SynBio technological translation and accelerating innovation are yet to be fully discussed.

4.1.2 A Chinese system for SynBio innovation

Chinese S&T system overview

A Chinese S&T system has been established since the end of the last decade to stimulate Chinese innovation development and economic growth. The earliest Chinese S&T system (1950s–1980s) was established and stabilised based on the Soviet centralised model. The current system, which has been transformed since the 1980s, has been systematically designed to respond to the 1980s' market-oriented economic reforms, focusing on reshaping the relationships between procurers and users of knowledge and innovation (Gu & Lundvall, 2006), encouraging the "technology market" and "private enterprises", along with China's economic reform to a market-oriented regime.

Main players of Chinese S&T system

The current system is under the guidance and governance of the Chinese State Council, which plays a prominent role in initiating and blueprinting national innovation strategies. Under the State Council, five ministerial departments—Ministry of Science and Technology (MoST), National Development and Reform Commission (NDRC), the Chinese Academy of Sciences (CAS), the Chinese Academy of Engineering (CAE) and the Ministry of Education (MOE)—play a direct role in designing and implementing innovation policies. A number of supporting departments, such as the Ministry of Finance, Ministry of Commerce, Ministry of Personnel, the State Intellectual Property Office, Ministry of Information Industry (MII), Ministry of Agriculture (MOA), and the National Natural Science Foundation of China (NSFC) have a significant influence on and support for S&T and innovation policies and implementation of essential resources.

Three of the main agencies for the governance of the Chinese innovation system are MoST, NDRC and CAS. MoST is responsible for designing the blueprint of Chinese S&T development and governance of the implementation as well as S&T infrastructure build and funding scheme, which is usually coordinated and collaborated on with the NDRC. The NDRC implements the S&T and national development strategies, ensuring continuous economic growth and social development, and implementing medium- and long-term plans, including the well-known Chinese five-year plan, which guides the overall growth

and development for the next five years. CAS also facilitates designing and implementing innovation policies, especially from the perspective of a think-tank; it not only leads numerous research institutes and labs, directly contributing to the research frontier, but also advises the central government on the design of innovation policies and social dynamics of innovation, directing innovation following the national S&T blueprints. Additionally, CAS collaborates with other agencies, such as the Department of Education to cultivate talent for the Chinese S&T system.

Funding mechanism and the transition period of the S&T system

Funding to S&T is made through a series of instruments of the government. Funding programmes and schemes are established to provide financial support, including funding for basic research, applied science, its commercialisation and research training. Financial support for basic research includes NSFC programmes, the MoST 973 programme and various programmes designed to develop human resources (Yangtze River Scholars Program, CAS 100 Talents Program, etc.) as well as funding for innovation and commercialisation, especially incentives for SME tech firms, and firms in key sectors.

With the Chinese government having learnt the significance of a market-oriented regime and private enterprises on the nation’s economic and technological growth, the national S&T and innovation strategies have shifted to encourage China's indigenous innovation and continue deepening the market-oriented model, shaping China into an innovative country by 2020. In response to the Innovative China 2020 and Made in China 2025 blueprints, the Chinese government has deployed strategies to promote industrial innovation and research competence. National medium- and long-term plans and programmes, such as Industrial Transformation and Upgrading Plan (2011), National S&T Infrastructure Programme (2014), 13th Five-Year Plan (2016), Made in China 2025, 10-year National Action (2015) and more recently, National Innovation-Driven Development Strategy, (2017) have been announced.

In response, the overall funding for innovation and technology translation has tremendously increased to stimulate the focus on indigenous innovation and private enterprise-led systems, especially after the Chinese Premier Li Keqiang, in 2014, called for

"Mass Entrepreneurship and Innovation", trying to further innovation-driven development and the consistent transition into a market-oriented economic regime. Emerging technologies such as SynBio have received significant positions in these documents, indicating a possible intention to achieve the next national goal of transforming China into an innovative country.

4.1.3 Basic scientific research in the Chinese SynBio sector

Global academic influence has played a vital role in Chinese SynBio research development. Attention was first given to SynBio in China when Patrick Cai and John Cumbers introduced iGEM to Tianjin University in 2005 (Tianjin University, 2017). In 2007, China first demonstrated its official academic interest in the SynBio area, with its first team from Peking University participating in iGEM, and its first joint research centre established with the University of Edinburgh (Tianjin University, 2017). The government then officially entered the SynBio sector with its national 322 Xiangshan Meeting held in Beijing (XSSC, 2008); the meeting brought together pioneers from both China and USA and discussed SynBio's strategic position in solving China's energy, food and environment problems, resulting in solid investment recommendations to the Chinese government.

China is steering its innovation through policies and political culture. A larger market potential than the Chinese market itself has been laid for Made in China 2050 with the establishment of "One Belt, One Road". However, China is yet to catch up to the most innovative companies in core technologies. For instance, China has had to import $230 billion worth of integrated circuits from other developed countries due to a technology lag. The main challenges China faces to its global ambitions perhaps include creating an enabling environment and nurturing talents in the Chinese system.

The Ministry of Science & Technology and the Chinese Academy of Science are the two state institutes responsible for funding and facilitating Chinese SynBio research, with over $38 million invested in SynBio research and more than 15 CAS institutes and key labs focusing on this field. While the Chinese Ministry of Science & Technology also stimulates the Chinese research ethics reviewing system, the State Development and Reforming Commission focuses on cultivating an encouraging entrepreneurial environment to

translate technologies at the national and regional level (OECD, 2016; OECD, 2007; World Economic Forum, 2016; MoST, 2017c; MoST, 2017a; MoST, 2017b; SynBioBeta, 2016; MoST, 2017a; MoST, 2017b). However, in comparison to nanotechnology (Jarvis et al., 2011), SynBio has not been entitled with a national steering committee, and the government has not planned to establish such committees for SynBio to encourage acceleration. The following figure (Fig. 3) illustrates the main policy and key regulatory agencies for SynBio in China.

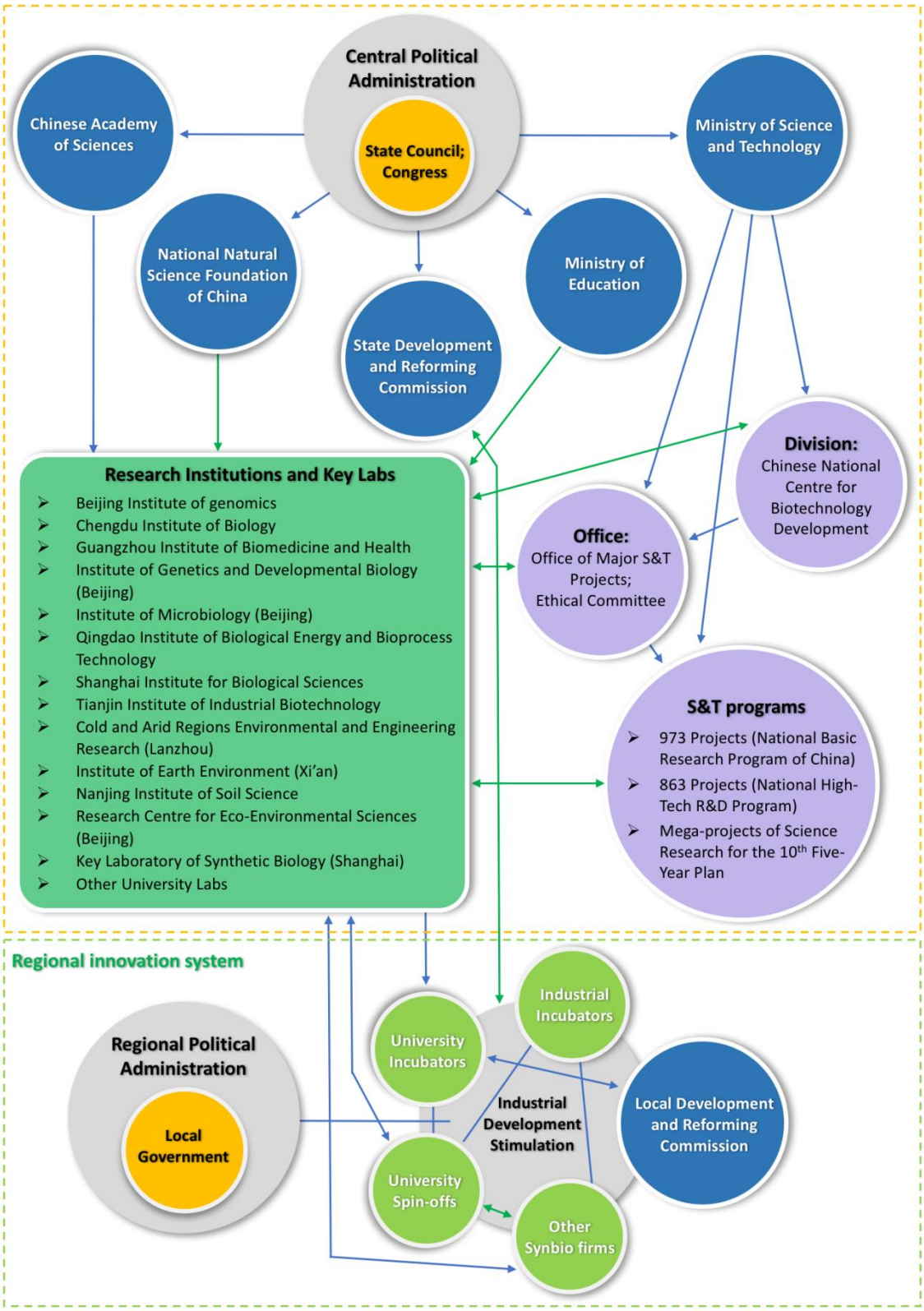

Fig. 3 Policy and key regulatory agencies for the SynBio sector in China *(Source: Author)*

As a result of responding to these strategic recommendations, the government-initiated investment agendas in SynBio research. Although China started late in the SynBio sector in comparison to the USA and the UK, its basic research indicates great capacity. Both patent analysis and bibliometrics from existing literature indicates that the Chinese SynBio publications and patenting are increasing, contributing though falling behind the US, UK and Japan, Chinese is still contributing an increasing literature in the SynBio sector (Zhang et al., 2011; Anon 2016; Pei et al., 2011; Liuyan et al., 2011; Oldham et al., 2012). A benchmark occurred at this year when four Chinese SynBio papers were simultaneously published in a *Science* issue (People.CN, 2017). A quick bibliometrics investigation indicates that the main research actors, mainly universities, include Chinese Academy of Science (contributing to 21% Chinese SynBio publication), Tianjin University (6%), Tsinghua University (6%), Peking University (4%) and Shanghai Jiao Tong University (3%). The following figure (Fig. 4) visualises the publication distribution in Chinese SynBio Sector.

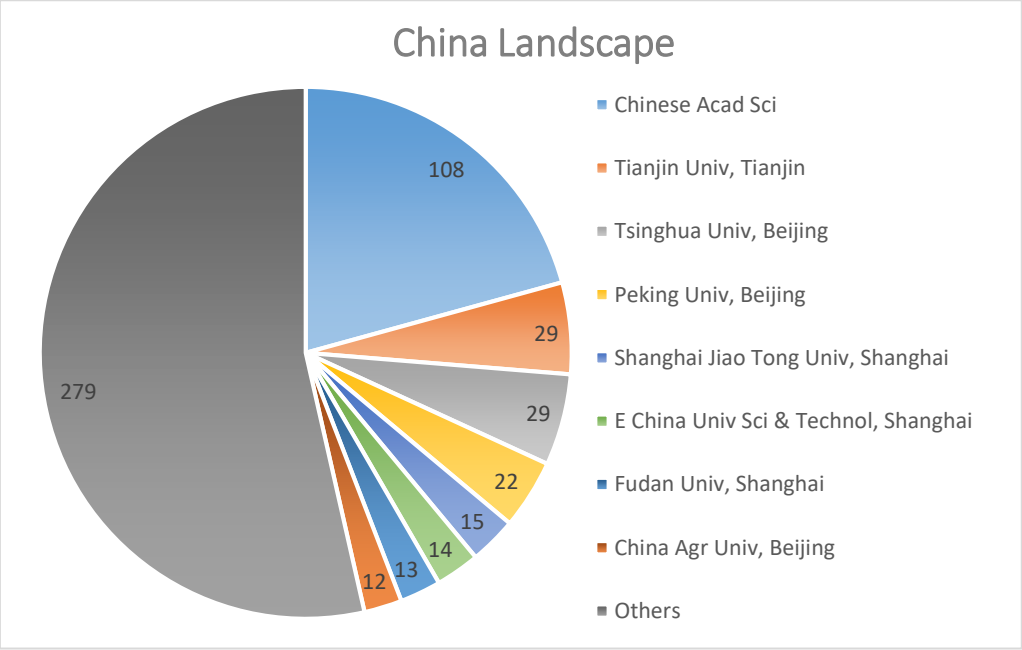

Fig. 4 Chinese SynBio publication distribution**(Web of Science search with key word reference)* (Shapira et al., 2017)

On the other hand, China has recently demonstrated its bold, if not aggressive, side in the basic science research areas, when more than two Chinese scientist teams reported on gene editing in human embryos (Nature, 2015). The research was criticised by other

researchers around the world by its ethics, wherein UK scientists specifically pointed out UK's contrasting regulatory approval on human embryos genome editing, which prohibits any using of human embryos that are older than 14 days (Callaway, 2016).

These disputes created enormous heat around Chinese SynBio research ethics and its reviewing system. However, it cannot disapprove Chinese research ethics review system as a whole. China has institutionalised research ethics review system since 2000, when MoST officially marched into accelerating ethics reviewing committees and ethics education in research institutions. This results in the issue of nine regulatory research ethics documents since 2000 (Chinese National Human Genome Centre, 2004), including the "*Ethical Principles of Research of Human Embryonic Stem Cells*". This regulatory document was jointly issued by Ministry of Science & Technology and Ministry of Health, at 2003, wherein an item of "*Strict prohibition against as follows: Human reproductive cloning; Putting embryos used for stem cell research into any uterus of women or animals; maintaining researched embryos for more than 14 days*" is explicitly stated (Chinese National Human Genome Centre, 2004).

The finding of Chinese landscape interview, on the other hand, demonstrates that the criticism of Chinese research ethics is not excessive. The Chinese ethics disputes are much focused on a scope of human genomes and human health, overlooking other aspects such as public engagement. Although ethics review systems, which usually consists of institutionalised lab safety reviewing check and research ethical committee, are observed in all the Chinese SynBio research institutions investigated, the majority of SynBio researchers do not possess careful considerations over the societal aspects of research and innovation. Four out of seven SynBio research respondents claim that they believe public's resistant perceptions of GM are deriving from the lack of knowledge of this particular technology. The following comment from a CAS researcher proves this point:

"These may be misleading to the general public as they do not necessarily understand the technology itself. They may fear just upon hearing the term biology."

Seemingly, the awareness of societal aspects of research and innovation has yet to be a popular concept among Chinese researchers; and has yet to be considered to be addressed in research community. The Chinese research community, therefore, has yet to grasp the comprehensive substance of societal aspects of research and innovation. Thus, the Chinese research ethics review system are facing practical challenges in practical execution, which interestingly, is the similar challenge that China faced with in accelerating commercialisation of the SynBio sector.

Chinese SynBio companies are centralised in Beijing, Tianjin, Shanghai and Shenzhen, where the key CAS institutions are located, with many companies started up by researchers from nearby institutes.

4.1.4 Social aspects of commercialising SynBio

China has recently realised the significance of technology translation and commercialisation. Although the Chinese SynBio roadmap and strategic steering are under the influence of the UK roadmap, the Chinese government seems to be catching up to the industrial scale of the UK and the USA.

However, the Chinese government has received criticism of its capacity to translate SynBio into commercialised production. The criticism, however, is not explicitly of the innovation ecosystem for SynBio. The Global Innovation Index indicates that China's knowledge impact has been boosted, whereas its knowledge diffusion remains at a relatively low level (OECD, 2016; OECD, 2007; World Economic Forum, 2016). In its report of "The Statistics of National Higher Education Science and Technology", MoST pointed out that patent transfer and licence income accounted for only 0.56% and 1% of research investment in 2014 and 2015 respectively (Ministry of Education of the People's Republic of China et al., 2016). In the SynBio sector, China shows considerable patent filling. However, in comparison to the USA and the UK, China is yet to make a large impact. Although patent filling does not fully represent technology translation or commercialisation, it emits signals of future commercialisation.

To accelerate technology translation and commercialisation, the Chinese government officially called for a technology translation revolution in 2014, when “Law of the People’s Republic of China on Promoting the Transformation of Scientific and Technological Achievement (Amendment)” was issued, wherein the government advocated a market-oriented principle (NPC.CN, 2009).

The Chinese government later issued a matching strategic plan (“Plan for the Implementation of Deepening the Science and Technology System Reform”) to transform China into an innovative system by 2020 (NPC.CN, 2015). To achieve this, the government amplified the role of industry in mobilising researchers for industrialisation of scientific and technological development. With this notion established, university spin-off enterprises have flourished as trends, although the entrepreneurial environment is yet to catch up with the competitive advantages that the top Chinese universities possess in the SynBio research field. In comparison to the previous disciplinal approach that the government adopted for managing university research for-profit spin-offs set up by researchers or/and researching students, particularly with those whose research was predominantly funded by the government, China has shown its enthusiasm for translating technologies into innovations regardless of whether the government is the main investor.

However, in contrast to the UK (e.g. UK SynBio Rainbow Seed Fund)(RSF, 2017), the lack of SynBio-specific industrial funding in China is a challenge to technology translation in the SynBio sector. Although it is disputable to what extent a government should control the SynBio sector for its development, a consummate ecosystem, especially a sound funding system, should be cultivated with assistance and guidance from the government.

The lack of tailored funding agencies and the concentrated, heavy investment in research institutions results in financing challenges that face firms. Consequently, firms mainly rely on four other forms of investment: research-associated government funding, government special funding (e.g. funding for sustainable and green goods), local government funding (through incubators) and VC (foreign VC).

Research-associated funding is mostly available for firms that are spin-offs of university research labs. This type of funding is very similar to research grants, which are allocated

through research institutions. University spin-offs access this type of funding through their research labs. The locations of Chinese SynBio may also prove the point that firms are closely linked with main research institutes/universities and local incubators. The following map (Fig. 5) illustrates the locations of SynBio research institutes/universities and local incubators.

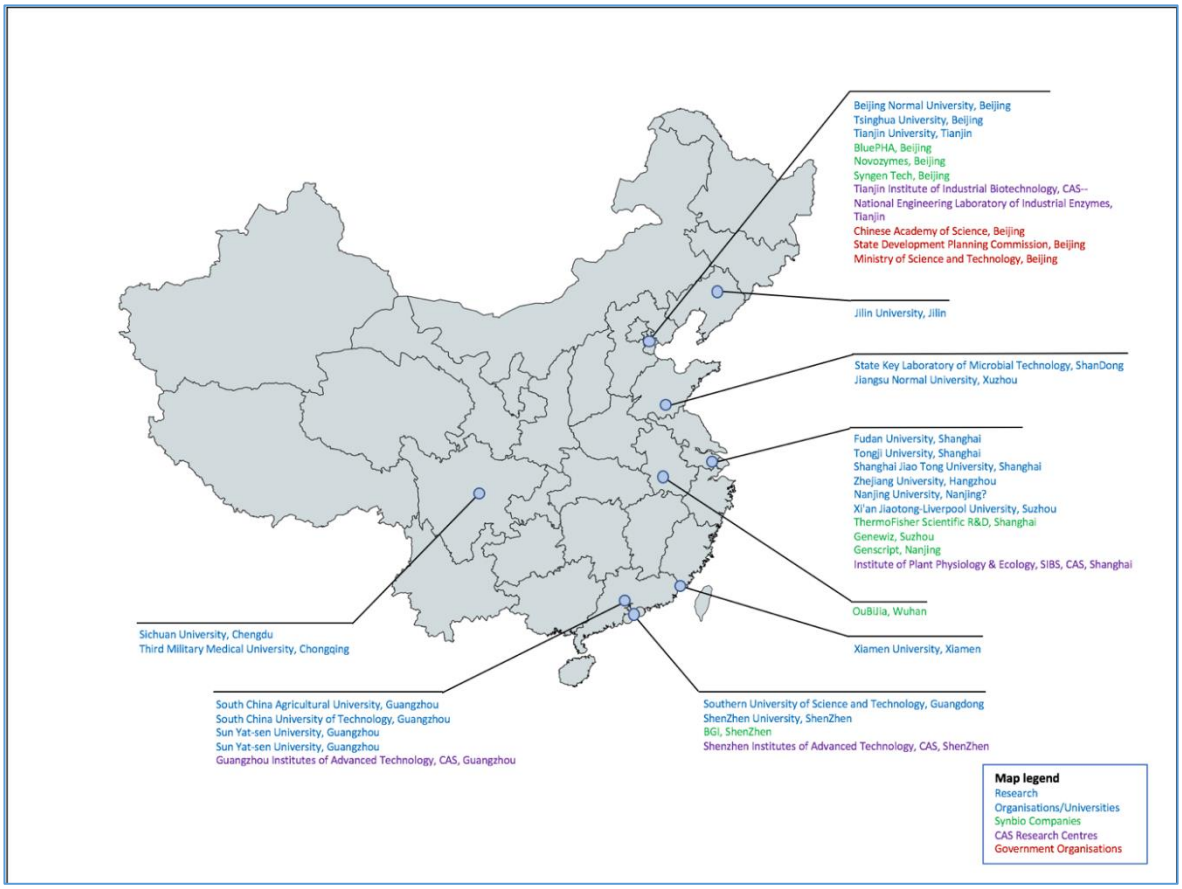

Fig. 5 Chinese SynBio sector landscape map (main players) (Source: Author)

However, heavy bureaucracy exists in both the application and reporting processes. Thus, it often fails to meet the expectations of this fast-moving sector. Similar bureaucracy applies to local government funding and special funding. Moreover, the strict high standards of the application criteria make funding difficult to obtain. For instance, in some regions, firms are required to possess at least one patent to apply for high-technology funding from the local government. This disrupts the financial aims of those start-ups that have great concepts. Consequently, many start-ups are seeking investments from VC. The attitudes of Chinese VC towards the SynBio industry do not improve the situation. Firms

(CNC1, CNC2) and investors (CNL8-15) claim that SynBio has not been well received in the Chinese VC field. Investors fear that SynBio will share the same unfortunate fate as GM. Therefore, some firms (CNC1, CNC2, CNC5, CN4) are seeking opportunities from foreign VC, and some university spin-offs partially rely on government funds allocated to their research labs. In contrast to the sceptical attitudes of Chinese VC towards SynBio, foreign VC shows great interests in investing in Chinese firms. The following comments from a CTO respondent (CNCI24) describes the current financing environment for Chinese SynBio start-ups:

"Tailored industrial funds for SynBio are yet to come forth."

"The examining and approving process of funding application becomes red tape; one of our funds that was allocated in August 2016 was applied for as early as December 2015."

"One of the challenges of Chinese VC is the lack of knowledge, insights and assessing mechanisms in this sector. Moreover, the personal relationship—the ideology of 'whom do you know'—still matters. Thus, the investment is not always allocated rationally."

Although the current financing environment for Chinese firms shows a mixed picture, Chinese investors hold high hopes that China will witness a blooming period of investments in the near future. One investor (CNL8-15) illustrated this point with the following comment:

"China is a big economy. With the last three prime ministers having engineering backgrounds, and with investing in biotechnology being the centre points of national S&T plans, I believe China can make these investments over longer timescales with great reliability."

Inevitably, perspectives of firms indicate that the sector is not satisfied with the current financing environment of the SynBio sector. Although SynBio enjoys a high strategic position in Chinese science and technology plans, no explicit strategic schemes are publicly available. Only a draft of the Chinese SynBio roadmap has been initiated and completed; the initiation was publicly announced by the president of the Department of Basic Research of MoST in 2012.

The compiling phase gathered diverse stakeholders—scientists and researchers from 973 and 863 projects, social scientists and industrial representatives by invitation—to participate in series seminars. The draft proposed a 50-year strategic plan to translate the SynBio technological platform into scaled-up production. This emphasises both basic research areas and commercialisation.

However, upon its completion, the Chinese road map may face the same destiny as the Chinese Nano Roadmap, which has never been published "because the Chinese government feared for the outcome of its publicity among the general public, with little faith that the Chinese general public would react positively". The author of the Chinese SynBio roadmap has claimed that the drafted document has been circulated in the SynBio sector. However, upon enquiry, most of my interviewees claimed that they do not have access to this document.

The main aim of drafting the Chinese SynBio roadmap is therefore questionable. Without publication or circulation, the document does not serve the purpose of facilitating SynBio commercialisation.

4.1.5 Public perceptions and societal research

China is facing two major societal challenges. One is the aforementioned research ethics, and the other is public perceptions of SynBio products. Although there is yet to be a particular survey conducted for SynBio products, similar surveys on GM indicate that Chinese customers have resistant attitudes towards GM foods and the general public is sceptical about the ethical approaches that scientists/the government adopted when advocating GM. For example, there was a hot debate when an American research team was accused of abusing Chinese children in their GM grain research without ethical considerations being applied (Charles, 2013). The government and the Chinese scientist who were involved in the research were blamed for their permissive approach. The ethical debate was then transformed into a political dispute, where the governance role of the government was questioned by the general public. The mistrust eventually exploded; the general public began to call specialists "specious-ists".

In contrast to the large investment in basic research, the government shows little interest in social research. Less than 20 Chinese main publishers are found in SynBio social research areas. The government seems to show less interest in understanding and communicating with the general public in comparison to other countries such as the UK and USA. This point is proved by the aforementioned unrevealed SynBio and nano roadmaps. A CASS social scientist enhanced this perspective with the following comment:

"The Chinese government rarely publishes the ethical issue report of emerging technologies because, from my perspective, some natural scientists and the government may be concerned that it may stimulate unnecessary public panic about the technologies; that it may stimulate media and environmentalists to mislead the perceptions. With which I disagree."

China shows a mixed picture of its social research on SynBio. On the one hand, the voice of social scientists is taken into account in decision-making processes, e.g. when drafting the SynBio roadmap. The government has also integrated social science perspectives into natural science research, e.g. synthetic biology programmes in the 973 project and 863 project are associated with the requirements for researchers to conduct public education and communication while researching. On the other hand, the voices of social scientists are weak in contrast to those of natural science researchers. The government shows little interest in investing in SynBio social research. China is yet to address the social aspects of SynBio in-depth as countries such as the UK have. A Chinese CASS social scientist whose expertise lies in the social aspects of SynBio, GM and nanotechnology proves the aforementioned discussed point with the following comment:

"The Chinese government currently has not paid sufficient attention to societal concerns of synthetic biology. The underlying reason may be the Chinese government has not considered SynBio as a mature commercialised technology yet. Thus, much less attention is paid to SynBio, in contrast to GM and nano."

China's social research cannot and should not be measured using explicitly Western criteria, which is often the case, because China and the West are distinctive culture clusters, where social behaviours and mentality differ fundamentally. However, it is clear that social

research has yet to be emphasised in China, and societal aspects have yet to be perceived, studied and comprehended under the Chinese context.

4.1.6 A unique Chinese system and current challenges for the SynBio sector

As argued in the previous literature chapter, the Chinese government plays a powerful and fundamental role in directing and shaping the innovation ecosystem. It is exceptional in the SynBio sector, although international influence seemingly speaks louder in the SynBio sector than in other conventional sectors.

Under the umbrella of the central innovation ecosystem directed by the Chinese central government, there are regional and local innovation ecosystems. These systems differ at the provincial, municipal and organisational levels. For instance, as discussed previously in the literature chapter, innovation strategies differ distinctively in Chinese state-owned firms and private firms, with the latter being more innovative and productive (Van Doren et al., 2013). Regionally, the local governments often offer various innovation policies and support. Arguably, the political atmosphere differs distinctively from region to region, especially for Chinese Special Economic Zones. For instance, when firm CNC5 was rejected by the Beijing and Suzhou systems before the Chinese government recognised SynBio's strategic position, the Shenzhen government was not only supportive but also impressed by their innovations, "luring CNC6 in 2006 with 10 million Renminbi in start-up fees and 20 million Renminbi in annual grants" (Nature, 2010, p.23). The following comment of a respondent from CNC5 describes the situation back then:

"They were in Beijing, couldn't get on with their establishment in Beijing. They joined CAS for a couple of years, but then that wasn't working. They must have really fallen out with all of their researcher lead in Beijing, then they had to basically leave Beijing and get as far away from Beijing as they could. Shenzhen really welcomed them."

In a Nature published interview, one the founders of CNC6, upon being asked why they had moved from Beijing to Shenzhen, responded with the following comment:

"In Shenzhen, the mountains are high and the emperor is far away" (Nature, 2010, p.23)

As evidenced, it is quite difficult to discuss innovation ecosystems for the Chinese SynBio sector without considering the role of politics and governance. Chinese regional innovation systems were discussed in the previous Literature review chapter, while their explicit impact on the SynBio sector will be discussed in the discussion chapter.

Conclusion: The situation found through analytical investigation is that, in comparison to the government's ambitions for the synthetic biology sector, its actions to support scaling up are lagging behind, particularly on technology translation and commercialisation. Nevertheless, the increasing awareness of the significance of technology translation, commercialisation and societal aspects in the Chinese SynBio sector demonstrates that Beijing's vow to make its position among innovative countries is not just empty rhetoric.

On the other hand, the empirical findings suggest that although the Chinese SynBio sector has a greater awareness of the social aspects of innovation in contrast to conventional sectors, there is yet to be comprehensive awareness and practice of responsible innovation. As argued in afore presented literature chapter, China's innovation ecosystem differs in its own right, wherein its dominant governance, distinctive regional innovation systems and explicit national culture all stand out on their own. It is, therefore, unwise, and perhaps unworkable to fit the exact European responsibility frameworks into the Chinese context. However, while China has prioritised its economic development in order to reach the "Innovation Made in China" goal, responsible innovation should and must be carefully taken into account, ensuring the optimum societal benefits of economic development and innovations.

4.2 A UK system for SynBio innovation

This section integrates the empirical data collected from the UK landscape interviews with government's reports and regulatory documents. A thorough document analysis was conducted, featuring literature, reports and other archival data. The UK landscape section aims to capture the latest picture of the UK system, thereby setting the background of firms' responsibility behaviours. It provides insights into the UK's SynBio research, SynBio social research, relevant policies and other societal aspects.

4.2.1 The emergence of the SynBio sector in the UK

The UK government recognised the SynBio sector as an emerging technology that could potentially boost the UK's bioeconomics as early as the 2000s. Although SynBio was first identified as a disruptive technology and then later redefined as a rather incremental technology in some specific areas such as chemical synthesis, its leveraging impact on the country's economy is nevertheless undeniable. The UK government, therefore, intends to establish a sound and efficient financial, organisational and policy support for the development of the SynBio sector to achieve a leading position in the SynBio sector globally.

The section below details the key players in the UK SynBio sector and its current landscape regarding basic research and commercialisation. The UK SynBio community has witnessed much effort by the government to make the sector thrive and grow; however, several concerns and worries stemming from its innovation policies and regulations as well the uncertainties of Brexit require adequate attention from policymakers and the industry.

The UK government initiated SynBio and established the Synthetic Biology Leadership Council to guide and lead the development of SynBio research and innovation in the UK. Since its establishment, the council has announced and designed two main strategic plans for the initial ecosystem and community build (2010) and further commercialisation plans (2017). Evidence indicates the initial success of the execution of these two strategic plans, with eight main research institutions and over 60 SynBio start-ups having emerged and been funded. The UK's SynBio landscape is flourishing more than ever.

4.2.2 UK SynBio research and innovation landscape

The following sections present empirical findings of the UK SynBio landscape. An overview of the landscape is first introduced, followed by empirical findings of the key aspects of the UK SynBio landscape, which are basic science research, technology translation, commercialisation, and societal aspects. These sections integrate the empirical data collected from the UK landscape interviews with government reports and regulatory documents. Although a thorough document analysis was conducted, featuring literature,

reports and other archival data, the legal documents and governmental reports are the only two secondary data sources for this section.

The UK has a rather different innovation system from the Chinese one; although it is challenging to map the whole UK innovation system due to its complexity, it is clear that the UK has established a sound system to stimulate, guide and support research and innovation.

As early as 2007, BBSRC and EPSRC (Synthetic Biology Leadership Council, 2016; BBSRC, 2017) initiated funding and prioritisation, under the lead of the BBSRC Bioscience for Society Synthetic Biology subpanel, resulting in £900,000 (Clack, Interview, 2016) being granted for the initial networks of SynBio. However, it was not until David Willets, the former Minister of Science, developed an interest in SynBio and positioned it as one of the great technologies in the UK industrial plan did the government fully recognise SynBio's strategic value. In response, the government established a government SynBio leadership council, which then led to two SynBio roadmaps, a community with over 1,000 members now representing a good cross-section of industry, academia, and many other stakeholder interests, and the second-highest public expenditure on SynBio in the world following the USA. While the first roadmap (2012) aimed to encompass the consummate SynBio community and a responsible research and innovation environment to achieve a global leading position, the second strategic plan (2016) particularly concentrated on technology translation and scaling up.

Two institutes were built with the particular purpose of accelerating commercialisation and innovations of the SynBio sector: SynbiCITE and OpenPlant. While SynbiCITE focuses on cultivating entrepreneurship and establishing a SynBio pipeline, OpenPlant aims at developing open innovation systems and tools to foster innovation. SynbiCITE has established a full SynBio pipeline through collaborating with 26 universities and 70 companies (SynbiCITE, 2017; Clarke & Kitney, 2016). It has also set up an example of successfully accelerating SynBio start-ups with its More Business Acumen training and Lean LaunchPad, aimed at creating 30 companies with 3,000 jobs and a turnover of more than a billion pounds a year. Although SynbiCITE has been effectively accelerating SynBio

commercialisation through its pipeline and start-ups, the UK is yet to see an enthusiastic, entrepreneurial atmosphere in the SynBio sector. In contrast to the number of SynBio start-ups in London universities, other universities and regions are far behind. For example, MIB only sees one potential start-up spinning off from basic research. Moreover, in contrast to the USA (Ho et al., 2016), the UK start-ups are less focused on the design and with a much smaller number, which is the frontier of the SynBio sector; the UK investment environment is more conservative and afraid of risks (Clarke Interview, 2016). The UK SynBio sector, therefore, faces a challenge to fully scale up and translate SynBio into commercialised economic products (UK Synthetic Biology Roadmap Coordination Group, 2012; Doren, 2014; BIS, 2012; Davidson et al., 2012; Ho et al., 2016). The following figure (Fig. 76) illustrates the UK SynBio landscape. The same publication distribution indicates that (Fig. 6) the main research actors are Imperial College London (9%), University of Edinburgh (8%), University of Bristol (8%) and University of Cambridge (7%).

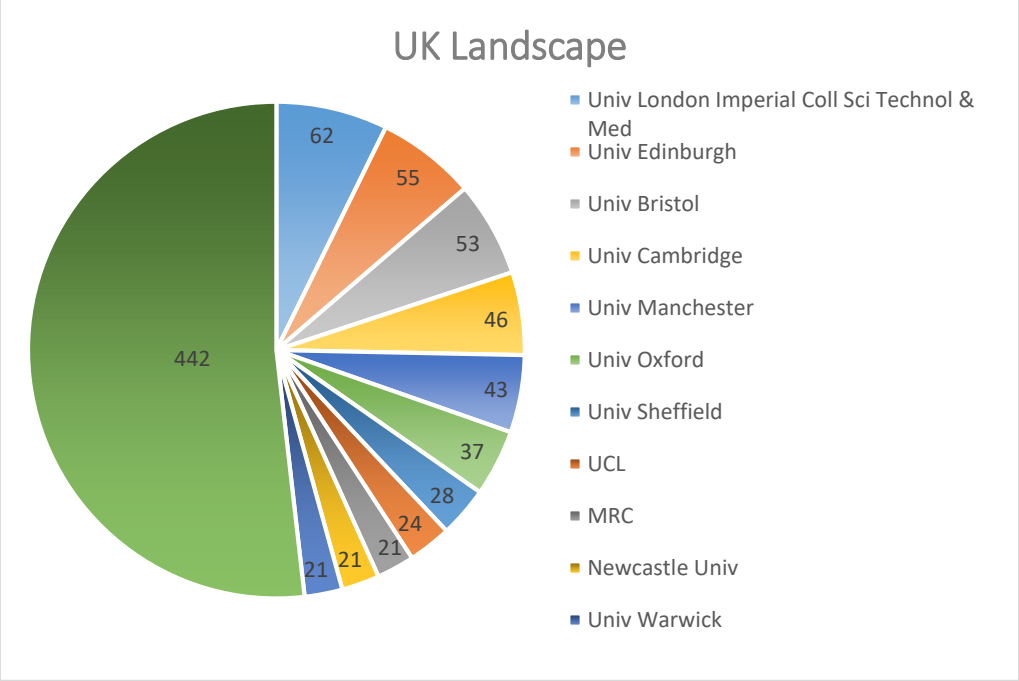

Fig. 6 UK SynBio publication distribution **(Web of Science search with key word reference) (Shapira et al., 2017)*

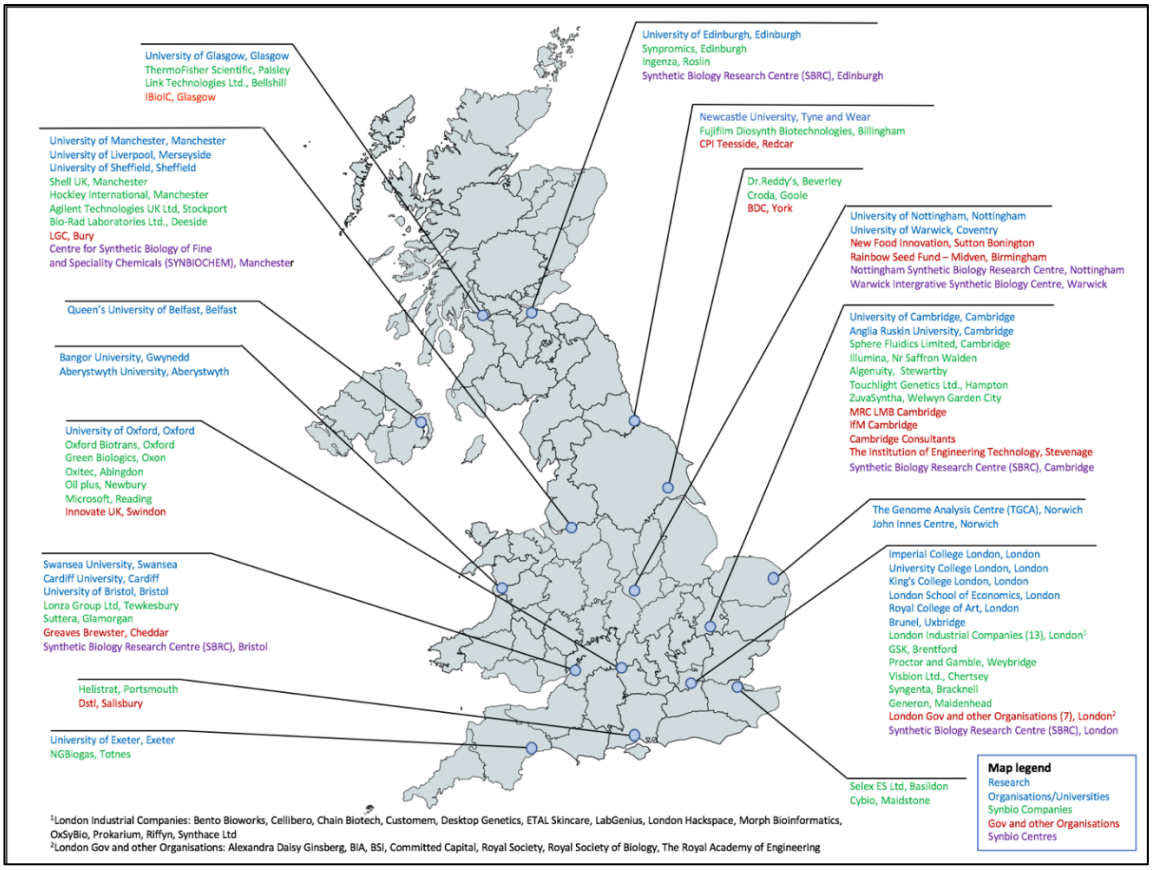

Fig. 7 UK SynBio landscape map (main players) (Source: Author)

The situation found is that the UK has successfully established infrastructure for the SynBio sector, including the increasingly evolving SynBio multidisciplinary community and a government leadership council. The UK SynBio sector, especially the research community, has heavily benefited from funding initiatives and development policies, putting the UK in a strong position to benefit from the initial investment. Because of inconsistencies with the first roadmap, the government SynBio leadership council issued the second map, focusing on technology translation. While the focus has transferred to technology translation and industrialisation, the sector faces uncertainties and potential challenges to scale up.

In order to drive the commercial translation of SynBio research further, the UK government has, in response to the SynBio strategic plans, invested over £300 million in establishing a technology translation chain, including the aforementioned multidisciplinary research centres, PhD training centres, and national support of SynBio commercialisation. The UK government supports SynBio commercialisation mainly through providing translation support and adequate funding for start-ups, which include accelerators and incubators, as

well as over £10 million of direct investments in SynBio start-ups, through rainbow funds for spin-outs and start-ups with possible co-investment from the UK or overseas investments.

As a result, the UK has almost half of the SynBio start-ups in Europe and has the second-highest number of SynBio start-ups globally after the USA, with an average of seven start-ups every year since 2000.

4.2.3 The debates around the definition of SynBio

The ongoing international disputes concerning the definition of SynBio have not yet been concluded (Nature, 2015[b]; Nature, 2015[a]; Ellis et al., 2011; Gibson et al., 2009; iGEM, 2015; iGEM, 2015; History & Open, 2003). Although researchers do not see the adoption of a precise definition as key for scientific development and potential applications, regulators may perceive it as a challenge to regulating and assessing SynBio. As discussed in the previous literature chapter, the dispute lies in the precise key terms used, and whether SynBio is a platform technology or not.

A Bibliometrics Web of Science search (Fig. 8) indicates that SynBio* (search key word reference: Shapira et al., 2017) is associated with a wide range of bioengineering terms. My interviewees, on the other hand, focused on several key words (Kuzhabekova & Kuzma, 2013; Benner & Sismour, 2005; Molecular Systems Biology, 2007; Ron et al., 2006; Trosset & Carbonell, 2013; European Commission, 2014; The European Commission, 2014).

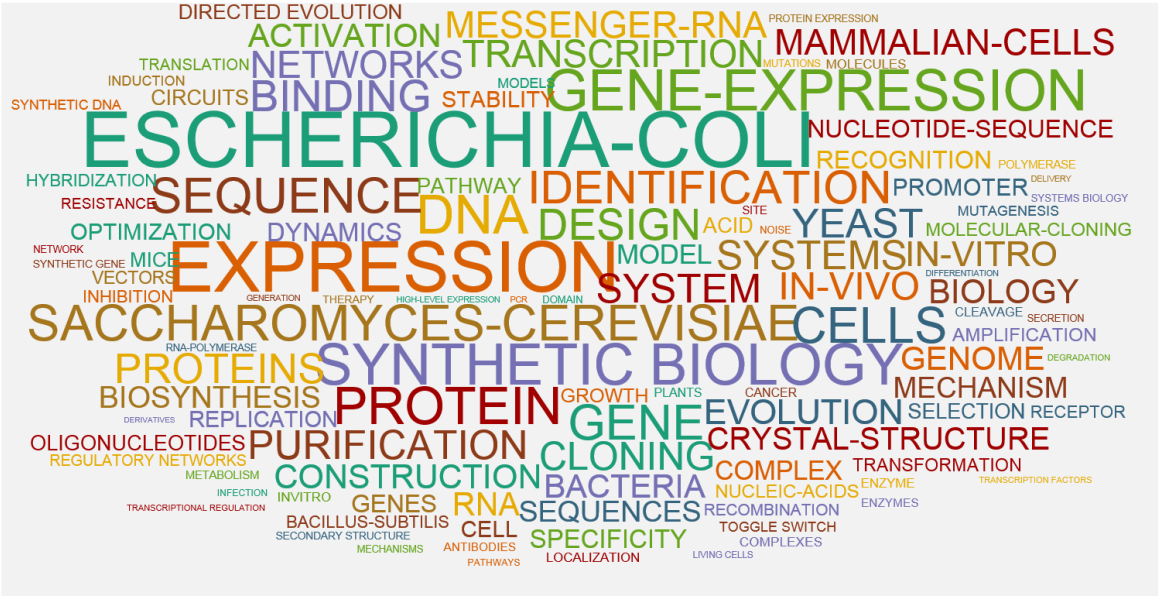

Fig. 8 Word cloud of SynBio (Source: Shapira *et al*., 2017)

The empirical findings suggest that although researchers define SynBio differently on the individual level, several key terms were briefly mentioned, which include, but are not limited to engineering, engineering approach and design. Regarding whether SynBio is a platform technology or not, researchers simply cannot reach a consensus, regardless of their research backgrounds or institutional backgrounds. The same applies to the industry, where various definitions are used not only by firms, but also by individuals from the same firm. Nevertheless, the two following comments, from P and J of Imperial College London, represent the two main definitions of SynBio:

"Yes (It is a platform technology). It's a bunch of enabling tools to allow the design and construction of biological systems that have particular purposes. Those tools range from across the world… Then, we have the genome construction side of things, which is a slightly different piece and that's where you're building completely new genomes".

"Well, it isn't really a platform technology, it's platform science at the moment that can be applied to different technology uses. The essence of synthetic biology is that one can engineer biology. The essence of engineering is design, and then building something, and then testing it. But we want to do more than just design, build, test and then better design. We want to create new things, but we also want to do this so we can manufacture at scale".

Despite the disputes, the concern, expressed by policymakers, is that not having a clear definition can create regulatory ambiguity. While a narrow definition may cause regulatory loopholes, a broad definition raises the question of what is covered and what is not.

4.2.4 Public engagement of research centres

Two main objectives are observed when research centres engage with the public: communicating science, responsible research and innovation, and engaging with the public in order to comprehend and learn from their perceptions. Depending on the purpose of events, these two main objectives can often be found combined. Centres are reaching out to larger audiences with various interests and backgrounds for a fuller picture of public engagement.

Research institutions often participate in science festivals and organise public education and open days for A-level students, high schools and primary schools. Although the designs of presentations differ, they serve as a means of cultivating the public's interest in science and technology, communicating the benefits and risks of certain scientific approaches, and learning from the public's perceptions of applications.

For example, at one of the Cambridge science festivals in which OpenPlant participated, a SynBio jigsaw game was presented where children could assemble various organisms with pieces of DNA parts provided. Upon completion, participants were asked questions such as:

"Okay. We have made an elephant whose ears turn purple when is cold. Do you think this is something useful? Is it ethical? Should scientists be thinking about doing this?"

These informal questions encourage initial thoughts on science and its societal aspects, serving as a good starting point for discussing responsible research and innovation. Although, some audiences are too young to participate in the post discussion, they can usually have conversations with parents on responsible research and innovation, communicating the concept of innovators' critical thinking of what they are producing, and focusing on aspects of economic benefits, social benefits and ethics.

Another example is the formal workshop, where research centres have dialogues with the public. One approach adopted by the John Innes Centre involves a variety of people from the general public, representing different genders, backgrounds and interests. Workshops often start with a very broad discussion, such as "What societal challenge is a scientist working on?" to see if any of the ongoing projects are identified as social challenges. The dialogues then move on to case studies of current projects, where the general public comments on the associated risks, benefits and alternative solutions. To achieve a better demographic diversity, the participants are canvassed in the street rather than on a campus. Arguably, those dialogues are difficult to measure and the centre tries to interpret them by capturing how people's opinions change through dialogues and workshops.

As difficult as it is to measure the outcomes of the engagement, MIB adopted a measurable means to visualise public perceptions. At a simple experiment conducted at an MIB open day for A level students, whose backgrounds included but were not limited to science, we asked students to choose the production approach that they believe is the optimum out of agricultural approach, SynBio approach and chemical approach. Prior to that, a brief introduction to the societal, environmental and technological impact of these approaches was presented. Results indicated that agricultural was equally favoured with the SynBio approach (Appendix A); eight of 20 students who chose the agricultural approach claimed that this approach was "natural", "more organic", and that "synthetic biologists are stealing famers' jobs".

While some of the activities are aimed at critical results and engaging the public's perceptions on research projects, some are likely to be one-off box-ticking activities. Activity types are deeply influenced by institutions as well as organisers. For example, the following comment by N from MIB describes how he perceives outreaching events and public engagement, and how that affects his event types:

"For me, it's about providing people with the opportunity to engage with science and to talk to a scientist. For me, if that happens, box ticked and we're done. Whereas, I feel public engagement is more about honing the specific message and getting a result from the people or opinion from the people or gauging what they think. We don't do as much of

that. We could do a lot more, but for me, at the moment, providing that outreach is enough".

Apart from public engagement, research centres also work with social scientists on TA. At Imperial College London, a small research event was cancelled because, during the collaboration with social scientists, natural science researchers realised that there was another optimum option available. However, not all the researchers had favourable attitudes towards responsible research and innovation. The two following comments represent two distinct perceptions of researchers:

"Let me say first of all that the idea that scientist like Dr. Frankenstein, "They can see this thing and don't think," we are human beings. We are consumers. We are intrinsically responsible because I don't think anyone wants to make something that would be dangerous. It's not part of our make-up because we are also members of society. Scientists are not some crazy people. I find this business so valid, yes, a kind of dichotomy between social scientists who feel that they have a better mastery of responsibility compared to scientists, quite insulting actually";

"Again, fundamental research. A lot of synthetic biology's building tools to make the manipulation of biological systems for specific application much easier, quicker, and faster and accelerate that. Therefore, in that context, I think the RRI narrative is probably important because you are in a position where you do need to think about some of these things, I think".

Other researchers argue that RRI is more useful when it is applied to innovation rather than fundamental research, as the majority of fundamental research is heavily driven by curiosity and the thirst for knowledge. A comment from Paul illustrates this point:

"Where RRI does have a really important role is when you start moving along the pathway from taking fundamental research into applications or into translations. Then I think it is really important. Therefore, there is this tension and the social sciences talk a lot about this. If you're doing fundamental research, you're not really thinking about what the applications might be of that fundamental research program, you're not doing any reflection at all at that point. You're thinking about, "How can I solve this? This

mechanism, this biological problem that's been built around for a lot of years. How do cells work at the detailed level?".

4.2.5 Open innovation

An IP issue was discussed in the Chinese SynBio landscape, wherein an open innovation policy or platform was advocated by the Chinese SynBio sector to freely share non-commercialised DNA parts, thereby reducing duplicate research work and investment in the sector (Saukshmya & Chugh, 2010; Zhang et al., 2011).

Addressing the same issue, the UK is seeking solutions through open innovation and open source equipment such as open Material Transform Agreement. While the former serves as a platform collecting DNA parts to share with the industry, the latter may facilitate freedom for the industry to operate at a technological level, enabling parts to be transformed and shared within the industry or to the third parties without IP restrictions. This allows and creates liberal open innovation at a lower technological level without restricting the ability of firms to patent and protect applications at a higher level. Although open innovation and open innovation tools face critical questions, such as "whether, and to what extent, policies of openness are appropriate for successful innovation with bioresources in synthetic biology and genomic" and "how does one implement openness effectively in bioresources intellectual property policies" (OpenPlant, 2016, p.20), open innovation is believed to play a promising role in creating more innovations and economic value for the SynBio sector. A comment from the business manager of the OpenPlant illustrates this point:

"So more value, more different applications but from the same technologies rather than having one company, for example, that holds one technology and uses it for one purpose, that you have this sort of communal pots of technologies that can be used for several different purposes. It's a way of increasing innovation and providing an environment where there are more innovations possible".

Currently, through its projects and OpenPlant funds, the centre is encouraging an open innovation environment and developing open source tools, including commercialised

applications, in the SynBio sector. Although nine projects have been successfully launched and a registry for plants' DNA parts has been under construction, the challenge of promoting open innovation with wider industrial engagement, thereby scaling up innovations of the SynBio sector, remains. Favourable voices are also heard from the firms collaborating with OpenPlant. In the following, a CEO describes her perceptions on open innovation in the SynBio sector:

"The patent and license model is that you make money out of protecting the things that- I think that's very much against the open innovation ideas. The club that I had was that of course anyone could receive the plasmids and all genes that I isolated, who is doing research. But if it was a company that wanted them, then they had had to pay me some money because it would cost them money to be able to clone those same things themselves".

4.2.6 A challenge in the SynBio sector - scaling up

Another challenge that the UK faces is to take a concept or an idea that works in a lab and apply on an industrial scale. The UK has shown its success in pursuing engineered organisms that behave obediently in labs, resulting in numerous academic papers and many start-ups, which was mentioned in the previously discussed technology translation section. However, there are yet to be a large number of successful cases of industrial scaling up. While it is feasible to keep SynBio organisms behaving well on a lab scale, it is challenging to pursue the same on an industrial scale. Variable factors, such as chassis, temperature, air circulation, humidex, media, feed stocks and production separation techniques need to be taken into careful consideration. Technicians are therefore required with expertise in fermentation, plant design or in other economically viable yield areas (EPSRC, 2013; Clarke & Kitney, 2016). Two comments from a CEO and strain manager illustrate this point:

"I think the biggest challenge for SynBio is scaling-up. This is certainly the biggest challenge for algae".

"It's got to be challenging because we don't have that scaling system that we can test everything in but until you actually spot that on the plant. You can not run the same

process on a plant because you have to consider where and how much amount of water, media you use, which is different from what you run in the lab. What if you are using a nice media in the lab but can not afford the scaled up amount on a plant? You can only have the clarity of these questions once you start off with the scaling up process".

While there is no proven model for successful industrial scale-up, some firms have pointed out that a testing system is appreciated to ensure that some products are economically viable and to optimise productivity. One of the CEO's describes this problem with the following comment:

"One of the learning lessons is to try and understand how you can have systems that are scalable, are relevant at lab scale that allows you to go to understand and be informed about how they would perform at large scale. In the UK, there are very few facilities that will allow you to do that. There's a few (for the sector), but for algae, almost none or pretty much none. What we're hoping to do here in the next few years is to building on our site which will include a pilot scale-up facility for algae, specifically for GM algae. We can have that resource available in the UK. But other algal companies, if they want to explore the space could come here potentially to use because it doesn't exist".

Another disputed area involves regulation: while some stakeholders are concerned about overlapping regulations, others argue that SynBio is under-regulated. However, the findings indicate that the SynBio sector is not under-regulated. International and European legislation systems regulate the use, sharing and transferring of genetic materials well, with regulations and conventions of the Convention on Biological Diversity, Cartagena Protocol and Nagoya – Kuala Lumpur Supplementary Protocol on Liability, UN Bioweapons Convention and The Australia Group Guidelines (Castro, 2015; Pauwels et al., 2012; Carter et al., 2014; Bar-yam et al., 2012).

However, the development of the SynBio sector may raise the question of whether digital genetic information should be regulated as genetic material. There is also debate about how to regulate and label the final products that have used GM but are not made from GM.

Conclusion: Findings indicate that the UK has successfully established infrastructures for the SynBio sector. The UK SynBio sector has now transferred its focus from the community establishment to technology translation and industrial scale-up.

On the other hand, although the findings indicate that research centres and institutions are raising awareness of and implementing responsible research and innovation at the managerial level, the perceptions at an individual level show a mixed picture. On a managerial level, research centres are found to collaborate with social scientists on various aspects, which include, but are not limited, to public engagement, technology assessments, science communication and other stakeholder engagement activities. While some of these activities have seen reflective results at the endpoint, such as risk assessment of technology, some are more likely to be one-off events. On an individual level, both supportive and sceptical voices are heard, where some researchers consider responsible research and innovation to be a great tool for performing responsible innovation rather than for criticising basic science research, which is considered to be mostly driven by curiosity and the thirst for knowledge.

5. Patterns of responsibility, perceptions and behaviours of Chinese firms

In order to achieve a leading position in the SynBio sector globally, Chinese firms need to address the societal aspects of SynBio. This chapter introduces how Chinese firms, in the context of the current domestic and foreign SynBio landscapes, perceive, motivate and implement responsibility and its activities.

Section 5.1 provides an insight into core motivations of firms' responsibility activities, with a focal point of the findings being on the inputs of firms' business strategies. Section 5.2 then elucidates how Chinese firms conduct responsibility activities by identifying types of activities observed in the study and components that influence the implementation of responsibility activities in Chinese firms.

In order to facilitate an understanding of firms' responsibility behaviours, two configurations of responsibility activities were identified and are introduced here: embedded activities and side activities. These two configurations of responsibility activities appear throughout this chapter and Chapter 6. They are identified in this research based on the extent of their direct engagement and involvement with decision-making processes of the main business activities, which mostly refers to "development, manufacture and sale of products and services" (BBSRC, 2015; GOV.UK, 2014).

Embedded responsibility activities, in this research, refer to those activities observed in firms that are directly involved with the main business decision-making processes. In-depth embedded responsibility activities are a component of the main business decision-making processes and contribute to the final decision. In contrast, side activities refer to those activities in firms that are not directly involved with the main business decision-making processes. Side activities do not engage with main business activities, nor do they contribute to the determination of main business activities. By contrast, embedded activities do influence final decisions.

Properties of these two types of responsibility activities will be discussed in the next section.

5.1 Firms' perceptions of responsible research and innovation

Chinese firms have a mixed perception of responsibility and its practice. While some Chinese firms have indifferent attitudes towards the concept of responsibility, believing that entrepreneurship itself is a type of responsibility to society and that additional contributions to society do not make much difference, other firms have favourable attitudes to responsibility and want to contribute to society.

Other firms link responsibility with research and innovation where a wider ecosystem is taken into consideration for innovation. These firms, instead of merely focusing on the business benefits of innovation or research, consider the wider benefits to society. Although their interpretations differ on a small scale on an individual level, depending on what aspects they primarily prioritise in the firms, the main focal points of responsible innovation are raising awareness and inclusiveness.

The first focal point of responsible research and innovation is raising awareness. Chinese firms, in comparison to UK firms, lack awareness that science and innovation co-exist with and co-depend on society together with other stakeholders in the ecosystem. Most of the Chinese firms do not interpret innovation such that the benefits and the risks of the science and innovations are considered for a wider system and for a longer period so that innovations can be sustained and so that the benefits of the innovations can be responsibly shared and enjoyed by the whole society.

The second focal point of responsible research and innovation is inclusiveness. Built upon the awareness that science and innovations do not and cannot exist on their own, that they exist in a wider system wherein political, economic and societal elements mutually influence each other, the idea that innovation decisions are solely made by people whose knowledge and perspective only represents one element of this system is therefore both scary and immature. The purpose of encouraging firms and research institutions to engage with a wider range of stakeholders is to learn from and absorb perspectives of others to perform a decision-making process wherein every possible alternative is inclusively considered. The inclusiveness also interprets in a manner by which the determination of innovation is executed with various perspectives representing these elements in the

system. Firms possess various focal points depending on what societal aspect they emphasise.

Firms' responsibility in innovation lies in the notion of CSR, where contributing back to the community/society is essential. However, this type of contribution may or may not be associated with innovation or research; it could simply be voluntary community work or charity. In other Chinese firms where responsibility is linked with research and innovation, there is an awareness that businesses ought to be part of the society to innovate sustainably and responsibly so that the benefits of innovations can be enjoyed with no associated risks for this generation or future ones.

The CEO of CNC2 describes his as follows:

"I think it is part of my personality to contribute back to our society and community, which includes solving societal challenges we're faced with."

5.2 Core motivations

This section presents the core motivations of Chinese firms for initiating and implementing responsibility activities. Several motivations are identified: 1) internal top managers' personal input-led motivation; 2) external international influence-led motivation; 3) strategic consideration-led motivation.

Chinese firms have a mixture of motivations for considering and implementing responsibility activities: strategic inputs and top managers' attitudinal inputs are two main motivations found in this research. This following section illustrates this finding. Section 5.1.1 presents and discusses the findings of how top managers' input shapes and influences firms' responsibility behaviours.

5.2.1 Internal - top managers' input-led motivation

Patterns of top managers' attitudinal input significantly influence firms' perceptions and activities of responsibility. It is observed that firms are more likely to initiate and implement responsibility activities when top managers have favourable attitudes. The level of top managers' attitudes to responsibility shows a mixed picture, where top managers who have

favourable attitudes towards responsibility tend to be more outspoken, enthusiastic or thought-rich when discussing organisational responsibility and social concerns of synthetic biology. This demonstrates the presence not only of awareness but also of well-developed perspectives, which are embedded in firms' core culture, core values and contents of internal training and lay the foundation for initiating and implementing responsibility activities in the firms.

There are also other factors influencing the perceptions and activities, which will be discussed in the next section. Six out of nine Chinese firms (CNC1, CNC2, CNC3, CNC4, CNC5, CNC7) were observed to have top managers with favourable attitudes towards responsibility, resulting in more responsibility activities and more embedded responsibility activities performed in comparison to other firms. These firms tend to conduct more than one type of responsibility activity and implement more whereas firms (CNC6, CNC8, CNC9) with top managers who have indifferent or sceptical attitudes were observed to have no responsibility activities and no intention to perform any.

Top managers' attitudinal input lays the foundation for initiating and guiding the implementation of responsibility activities. They initiate through forming and shaping firms' responsibility culture and values by importing their personal values, thereby raising the awareness of responsibility. A CTO's comment illustrates this point, as he describes how his CEO's (CNC4) personal beliefs of "contributing back to the society and communities" impacted on the firm's value in responsibility activities:

"He really believes in contributing back to the society, and communicates this value to our company as a leader. Eventually we felt: why not do these things, even though it may mean that we spend some money."

Not only do top managers' attitudes to society and community have an impact on firms' responsibility behaviours, but their attitudes to scientific responsibility also fundamentally affect firms' awareness of responsibility and their responsibility behaviours. For example, CNC9's establishment of an internal ethical committee originated from their founder's personal interest in ethical and social aspects of science, who is also involved in an ethical committee, the US National Bioethics Advisory Commission (NBAC). The aim of this internal

ethical committee derives from his perspectives of science ethics and responsibility: "advocating human equality, protecting the interests of individuals, personal privacy and information security and ensuring scientific and technological research meet social ethics". A comment from a staff member of this ethical committee elucidates this point:

"One of the reason that we established this committee is because of our founder-Dr.Yang. He is very interested in ethics of science and innovation. He believes that science should be conducted in an ethical and responsible manner".

A published interview with the founder of CNC9 also proves this point (China Economic Herald, 2012):

"Our discussion of bioethics has long transcended the ethics itself. Legal aspects and social aspects have become important parts of bioethics. In most recent years we have actively called for prioritizing the humanistic morals. Additionally, we also concern about the relationship between science and the public, cultural and religious diversity, economic, biological security and biological protection and with other new issues. We not only choose to explore the mysteries of life, but also bear the use of these research results for the benefit of mankind, other life and the obligations of nature".

In conclusion, top managers' attitudinal input contributes to mobilising and reinforcing the awareness of responsibility in firms. A positive correlative relationship can be observed between top managers' attitudes towards responsibility and firms' implementation of responsibility activities. Firms, where top managers possess favourable attitudes towards responsibility, tend to have larger numbers of activities or/and more deeply embedded responsibility activities. Firms where top managers possess indifferent or sceptical attitudes often perform a smaller number of activities or less deeply embedded activities, i.e. side activities.

Not all of the firms investigated possessed favourable attitudes towards responsibility activities, with some having indifferent and sceptical perceptions. The firms' attitudes were found to be closely related to the top managers' attitudes towards responsibility activities. Often, firms whose top managers had indifferent or sceptical attitudes towards responsibility were indifferent to or avoided responsibility activities. By contrast, firms

whose top managers had favourable attitudes were often involved in responsibility activities.

Although top managers' attitudinal input plays a central role in initiating and guiding the implementation of responsibility activities, other factors, including strategic competences, are also observed to influence the number and the type of activities that firms perform, which will be explained and analysed in the next sections.

5.2.2 Formation of the attitudes

With such a foundational role in initiating and guiding the implementation of responsibility activities, top managers' attitudinal input is one of the focal points of firms' responsibility activities. This element is then further investigated to understand how the attitude was formed. This section describes how top managers' attitudes, especially how the favourable attitudes were formed. Findings suggest that the influential components are personality, previous life experience and external training.

Personal values

In three out of nine cases (CNC1, CNC2, CNC4), the respondents claimed that performing responsibility activities in firms is essential. This reflects their values of responsibility. Some top managers (CNC1, CNC2) claimed that it was these values of responsibility rooted in their personalities, along with other significant factors, that drove them to enter this sector as entrepreneurs; a sector where they believed they could reform people's lives and provide potential solutions to challenges. Two young start-up CEOs elucidate why they believe starting a business in the SynBio sector is shouldering social responsibility in its own right:

"Part of the reason we intended to enter into targeted cancer vaccine market is because we (the CEO and CTO) believe that we can, and want to try our best to make the world into a better place, at least for these cancer patients".

"I believe one of challenges that the biology sector faced with is the shrinking job market, especially for biology PhDs and post-docs" …" Many of the PhDs and post-docs can not stay in biology industry because of the lack of job opportunities. By starting up a bio

company, however, we could offer positions for these who were trained and heavily invested by the government, thereby maintain and utilize their professional skills in this sector".

For these top managers, it is part of their personal beliefs to consider the social aspects of business and science. They could not identify the exact origin of their beliefs but thought that they were rooted in their personalities.

In the Chinese firms, only top managers were seen to bring in this awareness of responsibility, and to transform awareness into implementation. This was in contrast to the UK firms where a bottom-up approach was also observed. This will be discussed in the comparison chapter, Chapter 7.

Overseas experience

One of the factors observed in forming and shaping top managers' attitudes towards responsibility is their previous life experience, particularly their previous overseas experience. Top managers who had overseas life experience, either educational experience or working experience, tended to have favourable and enthusiastic attitudes towards responsibility. Six out of nine firms' top managers had overseas life experience; four had relatively long-term educational experience (PhD and post-doc) in countries including the USA, Denmark and the UK. The top managers stated that their overseas life experience had sharpened and broadened their perceptions of ethics and responsibility as individuals. A comment from the CTO of CNC6 illustrates this point:

"Pin (the CEO) may be influenced by the American ethical culture since he has stayed in America for so long… He, as a leader, imported the perspective into our firm."

However, it is unclear to what extent such life experience altered their values and perceptions of ethics and responsibility but it indirectly proves the idea of the underlying role that top managers' personalities play in initiating and implementing responsibility activities in the sector. It may have occurred as a result of the well-developed frameworks or codes of ethics and responsibility in science and research in the countries mentioned. Local culture, especially a human-oriented culture, may also influence top managers'

values and perceptions of ethics and responsibility.

iGEM human practice

Few Chinese firms have been derived from iGEM's outcomes, and those who were or who have interacted with iGEM teams claim that the experience empowered them with a deeper understanding of ethics and responsibility in a research and innovation context. The theoretical and practical codes of ethics required in iGEM train the top managers in working with codes of ethics and responsibility activities.

For example, in order to understand the public's perceptions on the result of the iGEM team's research that was being sponsored and monitored, a survey of public perceptions on "synthetic biology, global warming and biosafety" was conducted. Thus, the firm obtained substantial knowledge and awareness of the necessity to comprehend the perceptions of the general public. For instance, firm CNC6 conducted human practice for the iGEM team that they sponsored by presenting their project to the public and surveying their opinions (iGEM, 2015).

"We explained thorough detail of our project to many visitors including a museum staff who presented all projects on the museum website for online visitors. Many of the attendees have no background in biology, thereby we used the simplest way to introduce synthetic biology and show our project. Additionally, we gave an academic presentation to an expert from Fudan University. He was very drawn to the ribosome meter and predicted that this technology would have a huge application. During workshop, we were surprised to find that a little child was able to participate in the NYU-Shanghai exhibition. Giving education to next generation may be the best way to resolve the issue of global warming."

However, it is clear that in contrast to the UK cases, where most of the start-ups were derived from iGEM, Chinese firms are less influenced by iGEM, which may be a result of the Chinese education system where participating in iGEM is partially perceived as an event full of uncertainty. It may also be due to the fact that the Chinese education system still suffers from bureaucracy, and there is therefore a lack of a supporting environment for iGEM to flourish, especially in its early stage. In an interview with a former Chinese iGEM

team leader who was sponsored by the firm, she described barriers that she faced when initiating iGEM participation at her university at 2015. A comment from her is provided below:

"My university respectfully rejected our request to build an IGEM that summer, possibly because of the uncertainties of the competition itself" …" Moreover, professors were not so supportive due to the rejection of universities. We were, therefore, very grateful to be sponsored by this company-the other team perished by the lack of support".

5.2.3 Core motivation - strategic input

Business strategy was found to be another major driving factor of firms' responsibility activities. These strategic inputs include, but are not necessarily limited to, product acceptance, publicity (PR) and third-party requirements. Although top managers' personal attitudinal inputs lay the foundation for firms to initiate and raise awareness of responsibility, the Chinese firms perform most of their responsibility activities with consideration for the aforementioned strategic elements. Nevertheless, the types of activities are determined or deeply influenced by the strategic inputs.

B2C firms are often concerned about the acceptance of products, especially in the context of the previous infamous reputation of food safety, GM food and genetic therapeutics. Thus, B2C firms whose top managers support and believe in communicating and engaging with the general public choose to interact with and learn from the perceptions of the general public, regardless of whether the product is disputed or not.

For example, CNC1 organised two public exhibitions for the general public in national science museums and on campus in order to understand alternative perspectives from the public on their products. Their products and the technological essence were presented, and the firms' core value of bettering the environment elucidated, which resulted in great success of raising people's interest in their products as well as in SynBio itself. In contrast to what was expected, the general public did not have many opposing attitudes towards their products.

While their product (biodegradable plastic) arguably may not fit in the disputed areas, the

next example of genetic therapeutics proves this point. Firm CNC6, with its product fitting perfectly in the disputed areas, was observed to have a favourable approach because they created an ethical committee in the organisation to assess all the projects prior to launching. Detailed information is presented in the next section.

By contrast, B2C firms usually demonstrate an avoidant attitude when the top managers are rather sceptical or indifferent towards responsibility. When asked about social concerns in producing baby food supplements using SynBio, CNC7 demonstrated a defensive reaction, claiming that the reason why the general public are resistant to GM food is "because they do not necessarily understand the technology".

As evidenced, two distinctive approaches are taken by Chinese B2C SynBio firms. One is to avoid publicity. Another is to interact with and learn from the general public. The fundamental driving factor is not whether the products fit into the disputed area or not, as firms whose products fit this regime claim to undertake responsibility activities. Instead, the driving factor is the top managers' attitudinal input, which indirectly proves the significant and fundamental role of top managers' attitudinal input in initiating and implementing responsibility activities.

Additionally, it has been found that firms take the public's concerns into account prior to starting a business. For example, the CEO of CNC1 claimed that that one of the reasons they decided to start a business of wearable plastic rather than something else was because they were aware of resistance to GM food and other disputed areas.

Public relations - publicity

Some Chinese firms are motivated to embrace exposure and publicity; this is found in both B2B and B2C firms with various productions and applications. These activities are claimed by firms to be a "1+1>2" type of responsibility activity, where firms are exposed to publicity while performing activities, such as supporting local iGEM teams, organising SynBio summer camps and participating in charities, thereby achieving a win-win outcome. The common trait of these activities is that they are not embedded in any main business activities. Rather, they are side activities bearing greater similarities to CSR activities.

One example is the sponsorship of local university iGEM teams (CNC4), where the that provided the sponsorship claimed that part of the motivation was as follows:

"One of the reasons that we supported them is to announce our march into the SynBio sector, spreading our brand name around. Thus, we can gain some publicity through "advertising". We asked the IGEM team to put on the T-shirts with our logos during the competition. Although, it did not work very well as we expected, the close relationship we established with that university is a great gain".

Additionally, firms support the iGEM community by sponsoring the Chinese iGEM summit. One example is the 2015 Chinese iGEM summit, where both CNC1 and CNC5 jointly sponsored 34 teams from around the Chinese mainland. While both CNC1 and CNC5 supported the first Chinese iGEM, their motivations differed—CNC5 claimed that their aim was to accelerate the industry as a whole, whereas CNC1 claimed that their motivation was to expose themselves to publicity.

Another form of publicity exposure is found to accelerate the SynBio industry as a whole. Public education performed by firms is observed in the Chinese SynBio sector. This type of public engagement has never been seen in other industrial sectors. The aim of public education, according to these firms, is to raise awareness of how SynBio, as a technological platform, can potentially solve the challenges China is faced with, such as environmental pollution.

Third-party requirement - collaboration and policy requirement

Collaboration is not uncommon in the SynBio sector; it is, inevitably, an imperative trait. The challenging nature of commercialisation in the SynBio sector requires not only upstream firms collaborating with downstream firms, but also parallel firms cooperating for a better functioning SynBio community. International collaboration in the SynBio sector often raises issues of ragged standards; Chinese firms are observed to comply with international standards in order to obtain effective collaboration. For example, one of the underlying reasons CNC9 established its ethical committee was to catch up with international ethical agendas. Another firm, CNC6, claimed to collaborate with the FBI, the UK and Europe's political authority, to set up a standard screening process on an

international level, aiming at preventing bioterrorism. They operate a production screening process to identify their customers and their orders. Should any suspicious orders or organisations appear on the screen, a report is submitted to the FBI. A comment from the CEO elaborates on the details:

"Every single time we receive an order from US, from China or from any other countries, we have to subject this order to two screens. One is the mane company and the secondly is the sequence itself. FBI actually gave us two lists and if anything matches with this list immediately we have to stop processing the order. If it's on the first list, which is the terrorist list, this black list and you have to report to the FBI in terms of who ordered this and see if they are real terrorists. It depends on who ordered it. The Ebola is a very bad virus but there is a reason for using those genes, like doing research, e.g. vaccine. So if from say an order from a disease control canter, which will be fine. On the other hand, if it were from Iran, then it would be problematic".

In conclusion, the focal point of the firms' motivations is the attitudinal input from top managers, i.e. executive managers, including CEOs, CTOs, COOs, etc. The attitudinal input of top managers lays a foundation for firms' perspectives and attitudes towards responsibility activities. Top managers' attitudinal input contributes to mobilising and reinforcing awareness of responsibility in firms. Although the biggest motivation driving Chinese firms to perform responsibility activities is business strategy, top managers' attitudinal input determines firms' fundamental attitudes towards responsibility. Thus, firms whose top managers possess indifferent or sceptical attitudes are often have an avoidant or indifferent approach. Nevertheless, for most firms (CNC1, CNC2, CNC4, CNC5, CNC7), there was not one single motivation. Five out of nine firms were observed to possess a combination of the two core motivations. In the following, the two core motivations are discussed.

5.2.4 Core configuration of responsibility activities

The driving factors of responsibility activities in firms were discussed in the previous section, where top managers' personal input and firms' strategic management input were elaborated as the two main motivations in the Chinese study. This section aims to answer

the question of how firms perform responsibility activities. There are various types of responsibility activities in Chinese firms.

While top managers' attitudinal input plays a fundamental role in initiating and raising awareness and implantation of responsibility activities, strategic factors drive firms to design different activities. These factors include the aforementioned elements, such as product acceptance, third party requirements, public relations management, commercial transaction types (B2B, B2C) and intention to accelerate the industry as a whole.

While these elements have already been introduced and elaborated in the previous section, this section provides descriptive characteristics of the two main configurations—side activities and embedded activities. These characteristics are elucidated with examples that have not been presented previously.

Firms are observed to choose the type of responsibility activity (sometimes a combination of responsibility activities) depending on the strategic elements. Apart from two types of responsibility activity identified in this research based on their direct involvement with the main business decision-making processes, an indifferent and evasive attitude was observed in some firms. When the details of responsibility activities were requested, they responded in a non-straightforward manner, leading the conversation elsewhere rather than answering the interview questions directly. Some of the firms were not reluctant to demonstrate that they would rather not discuss their responsibility activities in detail. The following section discusses the types of responsibility activities and attitudes observed in the sampled Chinese firms.

Side activities have three necessary but not sufficient properties: transferability (same model of activities can be applied at different firms), repetitiveness (models of activities can be and are very likely conducted repetitively in firms) and replaceability (main business of firms is not directly affected by the replacement of activities). Examples of side activities are public science expeditions and supporting local iGEM teams, making documentaries of SynBio, participating in charities and so on.

Embedded activities are, as the name suggests, embedded in firms' main business decision-making processes. The main indicator of an embedded activity is that it has a direct effect on the main business activities. Characteristics of embedded activities are awareness, inclusiveness and responding inclusively. Awareness refers to the notion that science and innovations occur in a wider ecosystem where multiple aspects mutually impact on each other. These elements, such as innovation, politics, regulation, societal institution, environment, and the public's perception (social behaviours and psychology) inevitably impact on each other.

The Chinese firms did not demonstrate deep awareness as the UK firms did. For example, when asked about perceptions of responsibility in the SynBio sector, the Chinese firms often considered CSR as responsible research and innovation. Biodiversity and biosecurity were mentioned during the interviews only if it was initiated in the questions.

While inclusiveness refers to consideration for other stakeholders' perspectives when making a business decision, responding inclusively is the action, an organic result of applying awareness and inclusiveness that sets the direction of the subsequent trajectory of innovations. These dimensions will be elaborated again in the UK chapter, wherein more details will be presented with the UK cases. The next section elucidates some side activity examples that have not yet been presented in the previous sections.

Embedded activity example

Example A: Side activity example

Company basic information:

Company A is a biotechnology company focused on applying synthetic biology to scientific research and public healthcare. Since its establishment in August 2014 by a group of synthetic biology experts and entrepreneurs from Tsinghua University and the University of Essex at Beijing Zhongguancun Life Science Park in China, A has been committed to providing researchers around the world with high-quality, innovative technical services and products. Its services and products are designed to cover the whole industrial chain for synthetic biology, including various bioreagents (BioGeekTM), a sharing repository for

genetic elements, high-quality technical services and clinical healthcare bonded by common values. A's staff members are highly educated elites (master's degree or above) from prestigious universities or institutes around the world.

Activities:

Although few Chinese firms are derived from iGEM in contrast to the UK firms, Chinese firms are aware of and support iGEM teams and its community. In the previous iGEM section, the lack of a supportive environment in universities at its early stages was mentioned. It is therefore not surprising that firms stepped in to help. In two Chinese cases (CNC6, CNC4)**,** firms provided labs, research materials, mentorship and even trainings to iGEM teams. A former iGEM leader described the dedicated mentorship with the following comment:

"Michael (the CEO) almost dedicated around 30% or 40% of his working time mentoring us, where he would sometimes stay late with us practising presentations… We would not have been having this conversation right now, if it wasn't because of the support from Michael's firm."

Later, when the Chinese education system started to recognise iGEM, firms sometimes formed a joint sponsorship with local universities or high schools. However, "supporting local iGEM teams" is an activity that can be replaced by other side activities without any essential impact. It is transferrable from firm to firm with the same activity model and the activity model is probably operated repeatedly every year during the iGEM competition seasons.

The same properties apply to other side activities, such as creating SynBio documentaries, public education on SynBio and environment, organising SynBio summer camps and organising SynBio experimenting activities for high schools and primary schools. The next section gives some examples of embedded activities that have not yet been presented in previous sections.

Example B

Company basic information:

Company B was founded in 1999 with the vision of using genomics to benefit mankind and has since become the largest genomic organisation in the world. With a focus on research and applications in the healthcare, agricultural, conservation, and environmental fields, B has a proven track record of innovative, high-profile research, and has generated over 2,137 publications, many in top-tier journals such as Nature and Science. B's distinguished achievements have made a significant contribution to the development of genomics throughout the world. B's goal is to make state-of-the-art genomics highly accessible to the global research community and clinical markets by integrating the industry's broadest array of leading technologies, including B's own BGISEQ sequencing platform, economies of scale, and expert bioinformatics resources. B also offers a wide portfolio of transformative genetic testing products for major diseases, enabling medical providers and patients worldwide to realise the promise of genomics-based diagnostics and personalised healthcare. B's services and solutions are available in more than 60 countries and regions around the world.

Activities:

Currently, B-IRB consists of 20 volunteering members, with 12 internal members and eight external members. Additionally, B-IRB hires four staff members to process daily chores and other preparation materials. The 20 volunteers include experts in ethics, law, pharmacy, biotechnology and social studies, as well as residential community representatives. The 12 internal volunteers are selected from the volunteering B's top managers who can represent in their own research areas. Thus, the committee ensures its diversity and representativeness.

All projects have to be assessed by B-IRB; the underlying assessment criteria are associated with environmental and societal risks. Projects are expected to be sorted at quarterly committee meetings into three categories: Accepted, quick review and meeting review. "Accepted" projects tend to be repeated/continual projects and are similar to their predecessors. "Quick review" requires assessment from a small group consisting of a few

randomly selected committee members. “Meeting review” requires a formal meeting of all committee members. Members cast votes on the projects for both “quick review” and “meeting review” to accept or reject the projects. A project can only be “accepted” when it gains all the participants’ votes.

This committee assessed over 400 projects in 2015, with 33% projects assorted into "accepted", 66% assorted into "quick review" and the rest processed during meeting reviews. If a project was rejected during the meeting review, an amendment is required. Should the project be rejected once more during the committee meeting, it is more likely to face proposal rejection, and should not be proposed again within a year. A committee manager illustrated this point with an example:

"The ones received a service proposal of "talented genes” alongside a therapeutic and diagnostic proposal, where a group of B's researchers intended to analyse and identify children's potential talons from genetic perspectives. The committee believes that it is not ethical to identify children's genetic talents. Firstly, there is no scientific consensus that children's talents are inherited from genes. Secondly, the identification may cause psychological and cognitive changes to the children as well as the families. Additionally, the committee believes it is marketing propaganda to provide this service to children and their families. Therefore, the project received rejection and was not able to propose again within a year. The committee believes such marketing propaganda would damage B's reputation”.

B, in this case, was aware that science and innovations do not exist in a vacuum. Instead, they exist in a much wider ecosystem, wherein their products and research projects can and will have an impact on society. Therefore, risks and benefits must be considered. Built upon the awareness that science and innovations do not and cannot exist on their own, B then includes various perceptions and perspectives in the decision-making process. The committee consists of members with various backgrounds and expertise. The aim is to ensure that every possible alternative is inclusively considered. As a result, the “reflective response” is taken, wherein some projects are rejected and some are approved.

5.2.5 Commercialisation challenges

The Chinese SynBio community may face some challenges, thereby nullifying the effort and attention paid to social aspects and responsibility activities. The current challenges that the Chinese SynBio sector is faced with are discussed below. These challenges are mentioned and addressed by the Chinese firms.

Disputes of ownership and transport of genetic materials have been hotly debated in the SynBio sector. China is not facing a less dramatic situation. Apart from IP infringement issues, the Chinese SynBio sector struggles to cultivate open innovation under the current IP culture.

Commercialising SynBio requires large amounts of time and money invested in research. Thus, collaboration and open innovation is vital for the SynBio sector to scale up as a whole. Due to the nature of the SynBio sector, upstream firms (Design/Write) tend to work with downstream firms (Read), or vice versa, aiming for open innovation. However, a consummate platform is yet to be built in the Chinese SynBio sector for this purpose. A comment from a CTO (CNC4) illustrates this point:

"IP usually serves as a protection, however, if you become overprotective, you could hinder the industrial development… Non-commercialised parts should be able to be leveraged by other firms in order to save research time and energy, thereby promoting the whole sector… The Chinese IP system, from my perspective, is not well developed. How to build up a consummate system for this purpose is one of the big challenges here."

Moreover, it seems that starting a business in China requires extra effort in comparison with the USA and the UK, where a good relationship with local government is essential. Incubators, on the other hand, provide an intermediate system where local governments often offer benefits such as tax reduction, rent reduction, tailored networking, and entrepreneurial knowledge of firms in return, resulting in potential boom of the local GDP. Seven out of nine firms are located in incubators.

Firms choose incubators for various reasons. For instance, CNC2 selected Zhong-guan-cun Life Science Park as its incubator because of its funding offer for returnee entrepreneurs.

CNC1 chose XIN Centre not only for leveraging the accessory university labs, but also for its open, innovative and activated entrepreneurial atmosphere. A top-down perspective was also observed in a meeting with Suzhou industrial park regional government, wherein Governor Z explicitly claimed that firms choose them because “we have established the comprehensive soft and hard service platform system to help the companies reduce the R&D cost and accelerate transformation of the R&D results”. Additionally, a set of “regulatory application, investment-financing interfacing, business promotion, HR service and other professional services are accordingly offered”.

A further analysis of this point will be presented at the discussion chapter.

The empirical findings indicate that firms’ business strategies play a significant role in driving firms to implement responsibility activities. Although top managers’ personal input lays the attitudinal foundation for firms’ perceptions of responsibility, business strategies are the biggest reasons driving Chinese firms to perform responsibility activities. Additionally, the findings indicate that Chinese SynBio firms do not perceive or perform responsibility activities in a formative way, and that the types of activities vary under the influence of several internal and external factors observed.

6. Patterns of responsibility, perceptions and behaviours of UK firms

This section discusses the patterns of firms' responsibility behaviours found in this study. It investigates two main questions of why and how UK firms perform responsibility activities. It starts with findings of how firms perceive responsibility or the frameworks of RRI in some cases. Section 6.2 then provides an insight into the core motivations of firms' responsibility activities, with a focal point of the findings on the inputs of top managers' personal values. Section 6.3 elucidates and analyses how UK firms conduct responsibility activities by identifying types of activities observed in the study and identifying components that influence the implementation of responsibility activities in UK firms.

6.1 Firms' perceptions of responsible research and innovation

All of the cases investigated consider responsible research and innovation as an awareness-raising tool or process, by which a wider ecosystem is taken into careful consideration when innovating. Instead of focusing on innovations or innovators themselves, responsible research and innovation enables every decision maker to include and consider alternative perspectives prior to any decision. While a reflective approach is often adopted, decision makers can often encounter alternative outcomes.

Although their interpretations differ on a small scale on an individual level, depending on what aspects they primarily prioritise in the firms, the main focal points are raising awareness and inclusiveness.

The first focal point of responsible research and innovation is raising awareness. Decision makers include, but are not limited to, researchers and innovators. They are aware that science and innovations do not exist in a vacuum. Instead, they exist in a much wider ecosystem, wherein elements such as innovation, politics, regulation, social institutions, environment, and the public's perception (social behaviours and psychology) inevitably impact on each other.

In the following, top managers describe their perceptions of responsible research and innovation with comments, which prove the aforementioned point:

"I guess I wouldn't have a very sort of types definition of it, but it would be to look at various aspects such as public opinions, policies, the way in which the science is carried out, openness, social benefits, economic benefits, ethics and so on. To look at all of these, and to try and consider all of these things plus probably more that I haven't said right now. How they could influence the route that you take, and the endpoint, so that when you're looking at, for example, producing the product, you're looking at what the need is for the product, what the benefits are of purchasing that. Ultimately, it's about impact. It's about trying to innovate in a way that means that you get the best endpoint. But that's the best endpoint for everyone, not just for you, but also for society and everyone we're coming into and so on";

"A lot of it starts with an awareness, and parts of it might be done just as parts of reflection or consideration of the work you're doing and the way you do it, and discussions with other people that will help you to consider different options";

"I think it's naive to think that SynBio is always going to be the right solution. I think responsible innovation means you've got to look at both sides and say what's the alternative, what's the alternative to not developing this technology, to start this off with, what would be the loss to society";

"It's something I communicate to potential employees. Something that I communicate as part of our culture. Basically, my perspective is that, they (the employees) need to think of us as a synthetic biology start-up, as part of society. Considering the social dynamics of what all that means to the rest of society. Not as though we are separate from society, but as though we are part of it, we are drafting with it".

The second focal point of responsible research and innovation is inclusiveness. Built upon the awareness that science and innovations do not and cannot exist on their own, that they exist in a wider system wherein political, economic and societal element mutually influence each other, the idea that "innovation decisions are made solely by people whose knowledge and perspective only represents one element of this system" is therefore both

scary and immature. The purpose of encouraging firms and research institutions to engage with a wider range of stakeholders is to learn from and absorb perspectives of others in order to perform a decision-making process wherein every possible alternative is inclusively considered. Firms possess various focal points depending on what societal aspect they emphasise.

A comment from two CEOs (UKC2, UKC4) illustrates this point, wherein they emphasise the environmental aspect:

"If it's just about us making money then that's not the right answer. It has to be looking at what's the benefit to society, and what's also the potential risk to society and environment as a whole. There may be natural alternatives that might be slower, which have to be considered also. We do that too with algae. I think it's weighing all those things up and understanding actually what society needs and what the time horizon is for that, and including them in that".

"Well I think it's a very important part of what we do, especially because of what we do, engineering bacteria, you have to be very careful what you're doing and why you're doing it. You don't want to be giving the bacteria any competitive advantage over naturally occurring bacteria. Just in case something goes wrong out there, for whatever reason you have a big natural risk to the environment. We operate under some really good ethos of just because you can do something doesn't mean you should do it".

"Looking at the supply chain, how is something currently made? You then go in and say, 'Well, I don't know what the actual process is and I can actually make X tons of this per year at this price'. Well, what impact does that have on other supply chains? "

The last focal point attributed to a consummate responsible research and innovation process is reflective response If inclusiveness is a dimension by which firms integrate the alternative, divergent and diverse perspectives into the decision-making process, then "reflective response" is the action, an organic result of applying awareness and inclusiveness taken by firms to set the direction of the subsequent trajectory on innovations. Reflective response will be further elaborated with responsibility innovation cases in the following sections.

6.2 Motivations - top managers' personal inputs

This section presents how the UK top managers' attitudes, especially the favourable attitudes, were formed. Findings suggest that the influential components of the formation are personal values and beliefs, and external inputs.

6.2.1 Personal values and beliefs

Firms believe that considering and conducting responsibility activities reflects their culture and values as an organisation. Top managers in three firms stated that (UKC1, UKC2, UKC4) performing responsibility activities in firms reflects their personal values and personal beliefs as people who care about the environment or other people, who want to contribute to society and better society.

For instance, UKC4's CEO claimed that his passion of producing sustainable products is derived from his environmentalist values, because of which he enjoys seeing biodiversity and the environment flourish through responsible businesses. Two comments from the CEO explicitly illustrate this point:

"I think that because one of the thoughts, one of the big vision things for me, I'd say I'm a closet environmentalist. I love the environment. I love the natural world. And in the last few years, I have opportunity to be places in the world that are spectacular, biodiversity in Borneo, the rainforest in Borneo" …

"Responsible innovation, it has really resonated with me: thinking about how we can work with the environment in a positive way and draw off of it without impacting it, is a big challenge and that will be a massive vision and a massive dream".

The UK firms mostly adopt top-down approaches to raise awareness and initiate responsible research and innovation. However, the top-down approach was not the only approach observed. A case can be found where department managers take initiatives. A successful case is found in the context of a supportive environment, where the CEO and members of the board are supportive of implementing responsible research and innovation. The strain development manager of CBC4 initiated the awareness and practice of

responsible research and innovation out of her personal interest, for which she received immediate approval and support from her CEO and CTO. She indicated that the support she received really matters and that she would have failed otherwise. A comment from her illustrates how the CEO provided the support:

"After that it was just a case of 'Well, if you are interested in it then go ahead. Think about what kind of things you can put in place'. The good thing about us is that if you do not agree with something or cannot deal with something, you just stand up and say 'I don't agree with that', and our managers, the CEO and CTO, they will always listen to us."

This proves that the employee's enthusiasm in taking initiatives may be encouraged by the support received from top managers and these top managers who are supportive of implementing innovative ideas that are associated with risks are likely to provide encouragement, moral support and resources (Ramus, 2002; Sundbo, 2011). In this case, the CEO not only appeared to support and motivate employees but also to guide how much time and resources to input into the activity.

6.2.2 Motivations - external inputs

Apart from inputs from top managers' personal values and beliefs, firms also receive influence from external inputs to raise awareness of responsible research and innovation. These inputs include, but are not limited to, public reports (e.g. UK Synthetic Biology Road Map RRI section and other European SynBio ethical reports), public workshops and seminars (e.g. synthetic biology workshops/seminars' ethical discussion panel), iGEM human practice training and funding applications**.**

Four firms claimed to be inculcated with responsible research and innovation through external public training organised by the government and funding agencies, where the top managers' awareness of responsible research and innovation was reportedly cultivated through the process. Top managers then import the perceptions into the firms, integrating them with the core culture and values. For example, upon being asked where his interest and awareness of responsible research and innovation came from, the CTO of UKC3 replied with the following comment: *"Probably the UK government doing stuff with the workshops."*

Then he elucidated with an additional comment:

"The UK government has been really, really good about providing training, and seminars, and workshops to everyone. Myself and parts of the team have been to those training things and just learning about it, talking about it."

Not only the public training provided by the government raises awareness and shapes perceptions of responsible research and innovation, but information such as online government reports, policy documents and academic articles serves the same purpose. The findings indicate that some UK firms leverage online information to train employees on the principles and ideology of responsible research and innovation.

The UK's government public training and education was elucidated in the previous section on technology translation and commercialisation, where the government was observed to advocate the concept of responsible research and innovation by raising awareness in both the academic arena and the industrial sector. This proves that the government has successfully embedded awareness in the industry. A comment from a CEO illustrates the prevalence and its impact on raising awareness:

"The fact that, at least in the UK, it's always there. You're always reminded and you always have to engage with it. Of course, there are very good people. Academics who are well-known and who you can turn to. I think that's definitely something that's changed in terms of the infrastructure, the social infrastructure within the SynBio that just RRI has a place there now. It's clearly there. Whether you like it or whether you don't like or find it useful, it's on the map".

6.2.3 iGEM

In contrast to China, the UK has seen many start-ups derived from iGEM. iGEM has therefore played a game-changing role in these founders' career. Additionally, findings show that the human practice of iGEM fundamentally challenged their worldview of science and society, and raised their awareness of social aspects of science. iGEM encourages future scientists to think about their science outside the lab, to raise awareness of societal aspects of science and innovation—the impact of applications on politics,

economics, regulations and public acceptance. For instance, iGEM organises workshops where these topics are covered and openly discussed and the competition judges often follow up with ethical questions, such as the social challenges of commercialisation. Two start-ups emphasised the fundamental influence of iGEM on their perceptions of the social aspects of science. These perceptions are then imported into firms as core values and culture.

A CEO's comment illustrates this point:

"I think when you are starting off as an iGEM team, I think science students tend to look at it as a nuisance. It's like, "Why do we have to do this? I just want to do the lab work."; and then the awareness is developed by which they realise that "the technology or the science doesn't exist in a vacuum and if you really want to "change the world" or have an impact on it or have your science be more than just a publication. I'm not terribly interested in paper, that's why I'm not in university. But like then you have to consider those aspects as well otherwise yes you're doing originals. I think that's the thing though"

Another contribution of iGEM emphasised by top managers is its diversity in terms of gender equality, culture diversity and interdisciplinary scope. Although gender equality was not addressed by any firms when queried about their perspectives of RRI, these elements inspired their interest to explore the broader spectrum of SynBio applications rather than just the science. A CEO describes his first inspirational impression of iGEM experience:

"When I got into it, there was immediately this huge diversity of people interested in it. So, we had a philosopher of science on the team and we had a Bio Media Artist on the team, and I just found that very fascinating. That's always helped me see that there are much broader applications than just necessarily bioreactor chemical production."

Conclusion: In contrast with the Chinese firms, the UK firms all seemed to have a fuller comprehension of the societal aspects of science and innovation. Top managers of the UK firms investigated were all observed to possess favourable attitudes towards responsibility, tended to be more outspoken, enthusiastic and insightful when discussing organisational responsibility and social concerns of synthetic biology. In all cases considered, the top

managers were aware of responsible research and innovation. They integrated their perceptions into the firms' core values and culture.

In contrast to the Chinese firms whose most commonly adopted motivation is business strategy, the UK firms' top managers' personal inputs had a significant impact. Although their personal inputs originate from various sources, two main sources were found, which are personal values, personality and external influential factors.

6.3 Core configuration of responsibility activities

The UK firms are mostly observed to perform embedded activities, with a few side activities observed, such as science festivals and public education, which share similarities with the side activities adopted by the Chinese firms. Due to the word limit, this section only presents a few embedded activities that represent the different approaches adopted by the UK firms. The next section elucidates some side activity examples that have not yet been presented in the previous sections.

6.3.1 Example A

Basic information of the company:

Company A is a multi-national company that was founded in Oxford, England in 2003 to develop and commercialise advanced microbial technology for the production of renewable chemicals and biofuels. It has extended to the US and has over 100 employees in total. Firm A believes that they must use science and technology responsibly to design their customer solutions. They believe that they have an embedded health and safety culture and incorporate responsible research and innovation elements within their framework. They have also collaborated with other stakeholders to ensure that they ask the right questions, consider viewpoints from a range of stakeholders and do the right thing for the right reasons. For example, they have engaged with other educational organisations by visiting schools and universities as guest speakers, hosting school students on work experience and offering internship placements for university students. Their scientists also enjoy taking time out of the lab to share their passion for STEM subjects by participating in science festivals and similar events.

Firm A believes they conduct responsibility activities under the conceptualisation of responsible research and innovation in various ways, including participating in the Nagoya Protocol, which is an international agreement developed to create fair and equitable benefit sharing when accessing genetic resources to further one of the key objectives of the UN's Convention on Biological Diversity. To implement the Nagoya Protocol, the European Commission adopted Regulation (EU) No. 511/2014 in October 2014, which was made part of British law through the Nagoya Protocol (Compliance) Regulations 2015. One of the key principles is that anyone wishing to access genetic resources from another country must demonstrate comprehensive due diligence. They have claimed to be committed to a responsible approach to research and innovation, and have taken steps to implement the Nagoya Protocol in the organisation. When sourcing material within the scope of the Nagoya Protocol they take all reasonable steps to ensure that they and their suppliers have demonstrated appropriate due diligence and have complied with all national access legislation governing the access to and use of such materials.

A intends to collaborate with supermarket T in order to determine labelling rules for final applications that contain GM, but are not made of/from GM. In this case, the firm produces a GM algal ingredient, which is contained in fish feed and then fed to fish. These fish are eventually found on T's shelves. The firm, therefore, is keen to grasp T's perceptions of how the general public would perceive such a product and its labelling. The question is whether the general public would be interested or would be need to be included in the dialogue about the fact that these fish were fed a diet that had an ingredient derived from a GM ingredient. Firm A is also aware that the freshwater fish farming industry is facing a challenge where, with the growing demand for freshwater fish production, diseases will become more prevalent with the increased production of fish fed with natural ingredients. Therefore, this issue must be addressed for health and food safety reasons. The firm addresses the underlying reason for collaborating with T and the fish industry with the following comment:

"That goes back to responsible innovation. When does the synthetic biology way actually tilt the balance and say, 'Actually, this is the most responsible way of doing it as opposed to going after a natural route'. Those are the two sides to it. The plan at the moment is

that we would meet with this big fish feed company (and T), and they have already suggested that at some point."

The firm aims to facilitate fish companies in engaging with the public and creating awareness of responsible research and innovation*: "They have to include them in their thinking before they start to develop new ingredients or new technologies"*.

6.3.2 Example B

As discussed previously, firms perceive RRI as raising awareness and weighing up all the aspects in an innovation ecosystem. When collaborating with others, especially with companies upstream or downstream of the value chain, firms often take business strategies into careful consideration. Apart from these strategic factors, firms make decisions based on their perceptions of ethics and responsibility. Companies that firms work with are scrutinised according to their business ethics and cooperation responsibilities. Depending on firms' perception of ethics and responsibility, firms may find that such factors weigh heavier than other strategic factors.

For example, firm B refused to collaborate with an Indian company and a Chinese company as the former did not meet the regulatory standards and the latter failed to demonstrate their ethical standards. The CTO believes that it is ultimately their responsibility whom they collaborate with. The following comment illustrates this point:

"Ultimately, it started with us and we've got a control on whether or not we decide to go into that. And ultimately, when we come back to is, we can make money from that project. But it's the money that we're making, is it worth the impact potentially? It does, even though we may not be calling it responsible innovation, it's just an inherent part of what we are; it is integrated to who we are".

"Like for instance, we got an opportunity to go in on the grant with a group from here in the UK on the consortium that was involving India and it was potentially going to work with a GM firm in India. We decided that actually that wasn't responsible. Even though there would have been money that would come to us if we had won the grant and it would have been an opportunity for us, it didn't fit within what we believed was responsible, because the trials, and the tests, and the regulations in that area hadn't been established. For us as a company, we felt like the risk was too great to actually go into that type of project."

This proves that the firm has standard operating procedures to follow through the activities and they are aware that there are potential barriers, risks and benefits to monitor. Through collaboration with external entities, they request a standard that they consider to be responsible.

The firm, in this case, considers their responsible research and innovation standards when determining business decisions. They ask themselves what are the benefits for society, and if the answer is “We couldn't see clear benefits”, then they are not accepted.

“If you want to go forward with this as another group, you can do it but we're not going to be part of that consortium. We're going to choose not to be part of it.”

6.4 Commercialisation challenges and industrial solutions

Several themes are mentioned by the UK firms when asked about the challenges and significant factors of raising awareness and implementing responsible research and innovation. The firms identified training as a key means to raise awareness. Another emerging theme was communication with the general public.

6.4.1 The role of recruitment and training

Four firms explicitly addressed the role of recruitment and internal trainings to ensure the fundamental base of responsibility as well as raising awareness.

Firms often leverage recruitment in making sure that the job holders have the right skills, knowledge and attitudes to contribute to the firm to achieve its goals. One of the examples is firms who scrutinise potential employees’ personal values towards responsibility, thereby ensuring their values match with firms’ core values towards responsibility. This could happen during the first round of the interview or after. The approaches firms adopt are “people screening” techniques where questions or tests are delivered formally or informally.

UKC1 usually test whether the interviewees are aligned with the impact in resolving challenges that society is faced with that they intend to create with their SynBio products.

Tests are often designed to probe their interests. “In seeing us addressing the existential threat kind of problems, as opposed to maybe minor kind of problems…”

Tests vary from individual to individual, but the top managers of UKC1 prefer to observe how they behave instead of just getting their verbal answers. Interviewees may be put directly into tech meetings or strategy meetings with other employees and top managers to be observed. They may also be presented with an enormous workload to test if they are dedicated and passionate to tackle the problems.

“People screening” is also used by firm UKC2 and UK3, which focuses on personal characteristics. A comment from the CEO of the UK2 illustrates this point:

“We also just see that when we're screening people for interviews… Profits are important but we also care about people and doing good and also the environment. That’s a multi-level thing works in character, chemistry, confidence.”

A comment from the Strain Development Manager of the UKC3 additionally illustrates how they leverage the recruitment process to set up a base of responsibility awareness. Below, she elucidates that they often make sure that they understand:

“What kind of person they are, are they going to be a good fit for the group, and do they carry the things of value that we as a team and as an overall company do. I think that's a big part that you believe in the company values. Then, making sure that that goes into everything that you do day to day. Recruitment is absolutely part of it but having that values pretty much in place helps people to do that every day.”

Additionally, firms use training to raise awareness of responsibility and sometimes responsibility research and innovation, which can be organised formally or informally. In four cases, employees are exposed to training on aspects related to responsibility awareness, which may address explicit aspects of ecosystem awareness, environmental impact, technology translation, core culture, values of the firms. The trainings can also be organised informally. For instance, UKC3 claimed that although they are considering formalising the training of RRI, they currently only have informal training, through daily conversations and daily work.

"We are still trying to put a framework together for the company's responsible research and innovation policies. We do it (RRI) every day but we don't have a formal structure for it, if that makes sense. We can informally train them because we do it every day. It comes out in conversation on a daily basis."

Although most of the trainings are organised by firms for internal staff, trainings can also be delivered to external personnel. For example, through its firms' core values, customers' employees are required to mentor other people's businesses, where the mentoring may cover aspects of research, entrepreneurship, environmental impact and science translation. This type of mentoring consumes 5% of full-time employees' working hours. Thus, firms' perceptions of their core values and responsibility are spread. Moreover, they have developed responsible research and innovation policies for training employees, where they interpret the four dimensions of rri as follows:

Anticipate—describing and analysing the impacts, intended or otherwise (for example economic, social, environmental) that might arise from our research and business activities.

Reflect – reflecting on the purposes of, motivations for and potential implications of the research, and the associated uncertainties, areas of ignorance, assumptions, framings, questions, dilemmas and social transformations these may bring.

Engage – opening up such visions, impacts and questioning to broader deliberation, dialogue, engagement and debate in a diverse and inclusive way.

Act – using these processes to influence the direction and trajectory of the research and innovation process itself.

The firm proves with its activities and interpretations that it is aware of the narratives of responsible research and innovation and that they embed the awareness into daily activities.

6.4.2 Communicating with the public

Engaging with the public forms a large part of UK firms' responsibility activities. One example is communication with the public. In contrast to the approaches that Chinese firms

adopt, UK firms leverage communication as a bilateral learning process, where the firms do not intend to change or influence people's perceptions but rather learn from it. Firms thus have a comprehensive picture of product acceptance and prospects when it hits the market; additionally, it provides inspiration and diverse insights on potential projects, thereby optimising the project designs.

Another form of communication serves the purpose of side activities as part of public education. Although it appears that outreach events often reach out to those who are already interested, the findings indicate otherwise. Some key communication ingredients have been mentioned, such as openness, honesty and connecting with the customers on what they are interested in learning. For instance, when asked about his experience with public engagement, the CEO of CBC8 provided an example of successful communication with the British public in pubs. The communication was perceived as successful because, according to him, the majority of the audience was actively engaged and showed interest and because several farmer audiences demonstrated their interest over phone calls enquiring how SynBio could potentially improve the farming industry.

The following two comments illustrate his communication methods:

"Partly because the way it was presented and engaged and as a result I got invited to a second, one in Milton Keynes, so I gave a breakfast one. The first one was a dinner one then I got invited to a breakfast on 6 AM-7 AM talk in a place in Milton Keynes of their Rotary Club. Again a spectrum of about 30 people ranging from the late 40s all the way up the 70s. Massive, massive diversity across their backgrounds and careers and everything else. So it wasn't like a selected group of people only wanted to hear about synthetic biology. They did hear about it and I didn't get one question that actually said why are you doing that as well or anything like that. It was all, "Wow". That's really-the potential to have a benefit is really high";

"I went in with samples of food items and in the market now that they can eat that they have algae based products in them. I presented algae as an opportunity there about challenges that the world faces. And towards the end of that I talked about a how synth

really gave them a place in bio and those types of approaches to another level to use algae universally interested the group of people".

This point can also be proven by the GM Camelina oil public engagement, where Rothamsted UK conducted open, honest and fact-based public communication on their research—GM fish feed (BBSRC, 2016; 2017 The Harpenden Society, 2014; Rothamsted UK, 2017). This notion will be further discussed in the discussion chapter, wherein perceptions of the public, communication of innovations and societal aspects will be scrutinised.

6.4.3 Investment and RRI-the expectation from shareholders and the mediator role of CEOs

Three UK firms address the dilemmas between performing responsible innovation and investors' expectations. Investors, particularly VC investors, are turnover focused; in contrast to government funding (such as Innovate UK funding), VC investors often overlook other aspects of the business. Firms' relationships with VC vary from case to case; while some prestigious start-ups (UKC1) liberally choose VC based on their values of responsible research and innovation, others may not have such fortune. Thus, privately funded firms enjoy the freedom to fully integrate responsible research and innovation narratives into business activities according to their own preference and pace.

"Being a non-VC (invested firm) has been really good because sometimes you can think of it as we've been really just slow and steady. But there have been companies that have had the VC funding pulled and they're bankrupt... There have been several of those where one of our sister companies that we had close ties with, just here in Hertfordshire, they're a synthetic biology company. They went out of business last year (because the VC pulled out their investments) and it was really sad."

The top managers may play the role of mediators because not only are they capable of choosing VC based on firms' responsibility value and culture, eliminating those whose perceptions of responsibility do not match with the firms', but they are also capable of mediating between the investors and employees, providing support and guidance for those

who take the initiative in performing responsible research and innovation (UKC3—the bottom-up approach).

6.6 Conclusions

The empirical findings indicate that firms' top managers' attitudinal input plays a fundamental role in driving firms to form responsibility awareness and implement responsibility activities. Findings also indicate that the UK government's public education/training has successfully impacted on firms' perceptions and practices of responsibilities. All the firms investigated claimed to practise responsible research and innovation; embedded activities were found in all firms. In contrast to the Chinese firms, whose most common motivation was business strategy, the UK firms were much more influenced by top managers' inputs and external trainings, mainly organised by the government and other government agencies, such as funding bodies. The findings indicate that UK firms have much fuller narratives of responsible research and innovation and that the UK government has successfully mobilised the industry to raise awareness of responsible research and innovation.

Although the interpretation does not revolve around conceptual frameworks of RRI, it evolves into an awareness, a culture and company values of responsible research and innovation. The focal point of the findings are that the core motivation of UK firms' responsibility activities derives from top managers' inputs. Through importing them into firms' culture, values and daily business activities, top managers' inputs mobilise and shape firms' perceptions of responsible research and innovation, resulting in setting the direction and influencing the trajectories of innovations. Strategic motivations that are found in Chinese firms are not found in the UK counterparts. Additionally, the UK firms do not perceive or perform responsibility in a standardised manner and the types of activities vary under the influence of several internal and external factors observed, such as what the firms intend to focus on for responsible research and innovation.

Training repeatedly appears in the empirical data where firms and the government use it as a means of raising awareness of responsible research and innovation. In comparison to the mixed picture in academia, the industry seems to possess more accepting attitudes towards responsible research and innovation, interpreting it as a wider awareness that science and innovations do not exist in a vacuum but in a multifactorial ecosystem wherein the factors set the direction and influence the subsequent trajectories of each other.

However, the only firms who accepted my interview request were those who were willing to share their perceptions of responsibility. This point will be further discussed in the conclusion chapter.

7. Comparison studies and discussion

7.1 Introduction

Previous chapters (Chapter 5 and Chapter 6) explain and illustrate how Chinese and UK firms in the SynBio sector perceive and practise responsibility activities by presenting patterns of responsibility perception and behaviours with detailed examples.

This chapter provides a thorough synthetic analysis, answering the research questions by analysing firms' perceptions and behaviours through theoretical frameworks as well as comparing the patterns both within each country and cross-country.

To answer RQ1, firms' perceptions and behaviour patterns are analysed and cross-country cases are compared based on theoretical dimensions of responsible research and innovation, then responsibility innovation polices are analysed to understand how, and to what extent, the mixture of policy toolkits and the explicit policy tool impact the firms' perceptions and behaviours (7.2).

This research explores responsibility perceptions and behaviours of the emerging technology sectors in industrial settings, understanding and unveiling how explicit policies and other factors shape the emerging technology sectors in industrial settings. The patterns confirmed that there are various dimensions of the perceptions and levels of responsibility activities (7.2.1). A mixture of policy instruments shapes the perceptions and activities through various elements (7.2.2). The following section analyses these two aspects through theoretical frameworks of the dimensions of responsibility and policy instruments, answering RQ1. Then the other factors are analysed based on external and internal elements through the comparison of cases within each country so that RQ2 is answered (7.3). This chapter also discusses the significant mediating role of top managers in the firms in bridging innovation policies and actual practices by using tools such as trainings in the companies so that RQ3 is answered (7.4). Lastly, section 7.5 summarises the research findings, which enriches the theory of responsible research and innovation in the industry settings with original evidence and contributions on practising responsible

research and innovation through the mediating role of top managers with a mixture of policy instruments.

7.2 Cross-country comparison

7.2.1 Comparison of perceptions and activities

This section compares the patterns found by this research across countries in order to analyse how explicit policies and other factors shape the emerging technology sectors in industrial settings. The perceptions and behaviours are analysed based on the four-dimension framework of RRI, wherein the four dimensions are anticipation, Reflexivity, Inclusion and Responsiveness (Stilgoe et al., 2013) to understand how a mixture of policies shape and influence firms' perceptions and behaviours.

According to Stilgoe et al., RRI comprises four integrated dimensions (Stilgoe et al., 2013):

Anticipation refers to the process of analysing the possible risks and issues and what aspects and stakeholders should be included when considering and practising responsibility in the process of research and innovation.

Reflexivity refers to the process of reflecting and clearly defining the unknown and the known; therefore, associated risks, issues, dilemmas and stakeholders can be identified.

Inclusion refers to deliberately opening up dialogue, communication and engagement with other inclusive parties as well as stakeholders, which implies that all the possible stakeholders are involved in the process of decision making.

Responsiveness refers to a learning, or acting process where reactions are determined as a result of reflexivity and inclusion.

A comparison study across the two countries was conducted between UK and China to analyse the dimensions of perceptions and behaviours of responsibility in industrial settings, to further understand how explicit policies influence firms and further discuss the

deployment of policy instruments in implementing responsible innovation in industrial settings.

The Chinese firms and UK firms differed in their perceptions of responsibility and the four dimensions of RRI can be seen clearly in the operations of the UK firms.

Chinese firms mostly perceived responsibility in a manner that resembles CSR and engagement, emphasising the mindset of "contributing back to the society and community" and endeavours in side charity activities. Firms argue that owing to the vast investment and energy required, they can only upgrade their side activities if they make an adequate profit. Only one Chinese firm perceived responsibility in terms of science/innovation ethics.

In contrast, the notions of awareness and inclusiveness were often mentioned and interpreted by the UK firms, addressing the social factors of science and innovation. Raising awareness starts from the top managers in the firms with regard to the significance of responsibility and accountability of a business in societal settings. Inclusiveness then follows. Inclusiveness ranges from pre-established activities such as lean-launch interviews with potential customers to absorbing various perspectives of R&D projects from stakeholders. Societal factors such as environment, policies, and the public's perspectives are taken into account by the UK firms in the stage of "inclusiveness" when interpreting responsibility.

Raising awareness was mentioned in the previous chapter where UK firms' perceptions and behaviours were presented; it included two dimensions out of four of the RRI concepts—anticipation and reflexivity, where firms are aware (anticipate) that innovation does not exist in a vacuum. Instead, it exists in a much wider ecosystem, wherein elements such as innovation, politics, regulation, societal institutions, environment, and the public's perception (social behaviours and psychology) inevitably impact each other. Not only the needs of the innovation are considered (anticipated), but also potential risks and benefits to the society. Thus, the two dimensions of RRI are seen successfully embedded.

According to Stilgoe et al. (2013), open dialogues or open communication with other stakeholders is an essential part of responsible innovation. Inclusiveness builds upon the

dimensions of anticipation and reflexivity, where firms voluntarily include other stakeholders in the decision-making process. Although in the framework of "anticipation-reflexivity-inclusion-responsiveness RRI", "inclusion" emphasises communication, in practice, it consists of various means of action. The most important dimension in "inclusion" is that other stakeholders are involved in the decision-making process. "Inclusion" may easily become a box-ticking activity otherwise, without any impact on the actual business decisions, if done with mere engagement and dialogues. This dimension comes naturally with responsiveness, which means that responsible firms need to take action for innovation after anticipation and inclusion.

The last chapter illustrated the main responsibility activities that Chinese firms and UK firms adopted. Both Chinese and UK firms were seen to perform a mixture of responsibility activities where firms adopted either embedded or side activities or both in accordance with their business goals. There are some similarities and differences between these two countries' firms regarding the configuration of responsibility activities.

Chinese firms are more likely to conduct side activities, which include, but are not limited to, engaging with the general public, supporting local iGEM teams, participating in local biology education and so on. These activities have accelerated the agenda of engaging various stakeholders, especially the general public and have facilitated firms' goals of "contributing back to the society or biology community" or firms' strategic goals.

Embedded activities are often seen in UK firms, involving a thorough and encompassing reflective mindset in their business decision-making process, by taking into account various social aspects and benefits of stakeholders whereas most of the Chinese firms implement side responsibility activities.

7.2.2 A mixture of policy instruments

Government has a tremendous influence on business decisions regarding responsibility. Not only does the influence come from the explicit policy context, but also the manner in which policymakers cultivate the cognitive environment for the individuals who are subject to the policies. To deliver the explicit policies effectively, policymakers must consider the

cognitive environment beforehand. This research confirms that the government can successfully cultivate and reinforce the culture among individuals who are subject to the policies, therefore implementing policies effectively. Designing and implementing is particularly challenging, not only because the individuals who are subject to the policies hold various perceptions of responsibility, but also because of the uncertain effectiveness of the implementation, in this case the de facto responsibility activities in the SynBio sector.

This research confirms that the *soft instruments,* such as cultivating a cognitive environment for the policies*,* are effective in making disruptive changes in the industry setting. It proves what was argued by Linder and Peters (Linder & Peters, 1989), that "we will need to move beyond the abstract analytical scheme concerning policy instruments to a more complete understanding of the manner in which they are conceptualised by the individuals who must make policy decisions, and contextualised to meet the demands of particular situations."

Soft policy instruments include, but are not limited to, those that are not regulated or compulsory, but are embedded into the culture of the codes of action. These responsible innovation policies are much like a culture cultivator in which businesses are "influenced and trained" to have a more sophisticated awareness of responsibility in innovation. For instance, the standards of iGEM human practices function as soft policy instruments, with which participants are trained with portable knowledge and awareness of responsible innovation. Other soft instruments, such as public trainings of responsible innovation, also cultivate comprehension and raise awareness. The public trainings made available by the UK government enable the participants to gain profound perceptions of responsible innovation. It has proved to be effective in cultivating awareness among the participants; the impact of the public trainings was mentioned and identified by the interviewees numerous times.

Neither China nor the UK has established a set of hard policies with which firms or researchers need to comply. Thus, firms are seen with various perceptions and behaviours. It is foreseeable that standardisation needs to be established in order to set up a bottom line of responsible innovation and guidelines for firms' practices.

Soft policies - international influence

As elaborated in the previous chapters, the government or equivalent agencies (e.g. funding agencies/iGEM organiser) mostly offer training/seminar sessions to interested parties, especially researchers and industries, to raise awareness and comprehension of responsibility/science ethics. It includes training/seminar sessions embedded as part of the programmes, such as the human practice training in iGEM and RRI training in the Innovate UK funding programme. These independent sessions are open for public access. Both types of training/seminar have an impact on firms' responsibility perceptions and behaviours; they both lay the foundation for raising awareness and shaping knowledge. It is yet to become clear whether the external push force lays the foundation for shifting attitudes; the evidence indicates that for top managers who already have favourable attitudes towards responsibility, external push forces could enhance their attitudes and increase knowledge competence, but not essentially alter their attitudes of responsibility.

UK and China share some similarities and differences in how top managers' attitudes were formed. Both countries' top managers have had adequate influence from iGEM. In some cases, the human practice of iGEM stirred top managers' initial interest in responsibility or science ethics, and in other cases it increased top managers' awareness of responsibility or science ethics. iGEM human practice has played a role of initial training of "societal aspects of science" for some participants, which later on was imported into firms' culture and activities when businesses were established out of iGEM research. Evidence shows that more UK firms are exposed to the influence of iGEM simply because more UK firms were derived from iGEM research. This is not to say that there are more UK teams competing in iGEM than Chinese; rather, the UK iGEM teams are more likely to transfer their research into innovation. The underlying reason might be the under-addressed research transfer mechanism and environment in China.

7.3 Horizontal comparison – other factors

The previous section compared the patterns across the countries, in which explicit policies influencing firms' perceptions and behaviours were analysed. This section compares the patterns found by this research within each country in order to analyse how other

identified factors shape firms' perceptions and behaviours, facilitating the next discussion of the mediating role of top managers.

Three main motivations of firms' responsibly activities were explicitly identified in the previous empirical chapters, which include top managers' inputs, business strategic inputs and public trainings initiated by governments or equivalent agencies. Companies in China and the UK are motivated by different sets of elements in mobilising and implementing responsibility activities. While Chinese companies are mainly motivated by internal forces such as top managers' attitudinal inputs and strategic inputs, UK companies are mostly motivated by a mixture of external and internal forces, namely, top managers' attitudinal inputs and public trainings.

However, this disagrees with some of the theories from the literature. The literature argues that implementation of RRI may be affected by factors such as the firms' position on the value chain or the business nature such as whether the firm is B2B or B2C, but this research finds otherwise. While these arguments address the external and internal elements involved in responsibility strategies, they fail to recognise the one unique trend/essence of the SynBio sector. That is that collaboration is not uncommon in the SynBio sector; it is essential, regardless of the firm's size. The challenging nature of commercialisation in the SynBio sector requires not only international collaboration between upstream firms and downstream firms, but also between parallel firms, in order to achieve a feasible or even better innovation. Hence, firms seek international collaboration in order to complete value chains and firms seek profound international recognition. As such, some firms conduct responsibility activities to gain publicity as well as to form collaborations.

7.3.1 Strategic input

Strategic inputs are explicitly found in some of the Chinese cases, where firms conduct responsibility activities in response to management goals. However, this does not exclude the role of strategic inputs in the UK's industrial settings; rather, it emphasises the significance of strategic inputs in the Chinese industrial settings. Chinese firms mostly perform responsibility activities in response to two main external factors—the general market and partners on value chain. This is owing to the particular nature of the SynBio

sector; it is an emerging and internationally interactive technological approach which was born in the context of previous ethical disputes around GM and nano. Thus, while US and EU firms are addressing science ethics and responsibility, Chinese firms must seek similar standards when forming business partnerships with them. Additionally, the internationally interactive community of SynBio requires firms to seek not only a national market, but, most importantly, an international market. This is also proved by the data where the Chinese firms interviewed hold a larger market share in the global market than in the national market.

7.3.2 General market

The SynBio community, in comparison to other industrial sectors, is fundamentally more globally collative, benefiting from the international value chain. Having understood this significant characteristic, Chinese firms seek not only national but also international recognition in the SynBio community; therefore, some firms choose to sponsor local iGEM teams, aiming at utilising this international platform for publicity. This not only draws the attention away from the national SynBio community among researchers and other interest parties, but also attracts the attention of the international one. Noticeably, China's new technology and science policy, aiming at transforming China into an innovation country by 2050, explicitly emphasising the roles of several emerging technologies including SynBio, which has stirred up confidence and ambitions in the Chinese SynBio community. Thus, the Chinese SynBio community is mobilised to compete on the international platform and aim for a leading position.

In contrast, the UK firms are not observed to explicitly conduct responsibility activities in order to seek publicity in the SynBio community. This may be the result of a well-established UK SynBio community and platforms, owing to the initiatives established by the UK SynBio leadership council. With a promising number of SynBio conferences, research platforms, opening meetings and SynBio hubs where ideas, perspectives and state-of-the-art research can be shared and discussed, the UK SynBio firms may find a well-established system without seeking an alternative platform, whereas the Chinese firms

may feel rather isolated without a functioning communication channel. Hence, they seek information, attention and recognition from an alternative platform.

Additionally, owing to the lack of adequate funding for the Chinese SynBio sector (see analysis in Chapter 4 and Chapter 5), most of the Chinese firms interviewed operate a gene service for the international market (largely European and North American market) in order to sustain the investment in SynBio R&D.

In contrast, this motivation does not stand out among UK firms. This may be explained because 1) the UK firms receive better systematic financial support from the UK government with a larger amount of direct funding for the SynBio industry, whereas the Chinese SynBio sector has to compete with other emerging technologies for funding and other resources (see detailed analysis in Chapters 4, 5 and 6) and 2) UK firms are less likely to seek an alternative platform rather than the one established by the UK government.

7.3.3 Value chain

Another strategic factor that Chinese firms consider when performing responsibility activities is the international standards presented and required by other firms on the value chain.

For example, one of the underlying reasons CNC8 established its ethical committee was to catch up with international ethical agendas. Another firm CNC6 claimed to collaborate with the FBI, the UK and Europe's political authority to set up a standard screening process on an international level, aiming at preventing bioterrorism. They operate a production screening process to identify their customers and their orders. Should any suspicious orders or organisations appear in the screen, a report is submitted to the FBI.

This research did not find any associations between firms' perceptions and behaviours and the format of firms' business (for example, B2B, B2C or other business formats); therefore, this research does not support the argument that businesses differ in perceiving responsibility or performing responsibility activities due to their business nature.

7.4 The mediating role of top managers

This chapter discusses the significant mediating role of top managers in the firms in bridging innovation policies and actual practices by using tools such as trainings in the companies so that RQ3 is answered (7.4).

The previous sections analysed the mixture of policies and factors influencing firms' perceptions and behaviours; these explicit policies and factors eventually shape the perceptions and behaviours by shaping firms' culture and daily activities through the vital role of top managers. Hence, this section analyses the mediating role of top managers and training as an effective tool.

Chinese firms and UK firms share similar characteristics when considering top managers' attitudinal input in initiating, leading, implementing and evaluating responsibility activities. There is a clear positive correlation between top managers' attitudinal input and firms' perceptions and behaviours of responsibility and responsibility activities; it lays the foundation of firms' perceptions and activities. Firms, whether Chinese or UK ones, where top managers have favourable opinions on "responsibility" or "contributing back to society/community" are seen to have a positive, responsive attitude to responsibility and are seen to initiate responsibility activities. Nevertheless, although top managers' attitudinal inputs set such a foundation within firms, the actual landscape of perspectives and activities are under the influence of external inputs and strategic inputs. This point will be further analysed and illustrated in the next discussion section.

Top managers often mobilise and engage their employees by embedding their attitudes towards responsibility in firms' culture, daily business activities or both. Depending on what responsibility activities firms conduct (side activities or embedded activities), top managers usually embed these attitudes at various levels in firms. Cases are found in both UK and China that some firms introduce responsibility as companies' written values, that some embed the awareness of responsibility into firms' activities through refined behaviours (for example recruiting people who hold comprehensive awareness of responsibility) and that some implement both (for example B). It is more likely that firms will perform embedded responsibility activities when top managers' favourable attitudes are embedded in the

company culture and business decision-making processes; otherwise, firms are more likely to conduct side activities. This is a reasonable phenomenon considering embedded activities require various dimensions in decision-making processes, which include, but are not limited to, awareness and, most importantly, reflection. As such, the UK firms are more often seen embedding responsibility into the companies' culture and business activities. However, this study did not find a solid cause-and-effect relationship between "writing responsibility into company culture" and "conducting responsibility activities", meaning performing responsibility activities does not necessary require formal regulations but rather, it depends on attitudes, culture, awareness and mindsets.

7.4.1 Internal - top managers' personal beliefs

Another similarity between UK and China is that both UK and Chinese firms' top managers considered their personalities or personal beliefs as motivations.

Although the two countries differ in how top managers' personal beliefs were formed, Chinese top managers explicitly emphasised the overseas experience, mostly that of higher education and lab experience, which shaped their perspectives of responsibility or societal aspects of science. These Chinese top managers received their overseas experience in countries where science ethical codes and protocols are relatively well-established in accordance with the development of science—USA, UK, Denmark and so on. Although it is difficult to measure the amount of influence that the Chinese top managers received or to determine value later on embedded into the business, one can argue that the overseas experience shaped and sharpened their perspectives of responsibility or science ethics.

Some top managers argued that the greatest influence was is their personal belief to care for the environment and care for the societal aspects of their businesses, without being able to identify the particular elements that formed these beliefs. The influence of personal beliefs was also found in some of the Chinese cases where the top managers considered it part of their personalities to contribute back to society and the SynBio community. Although top managers in both countries emphasised the role of their personalities and personal beliefs in mobilising and guiding responsibility activities within firms, the components of their personal beliefs differ in that, while the Chinese top managers' beliefs

fit in the spectrum of CSR conception, the UK top managers, in addition to that, are aware of the variety of societal aspects of science. This difference may be owing to the public training initiated by the UK government and the equivalent agencies, which reshapes top managers' perspectives of responsibility and responsibility activities through open-access workshops, seminars and other resources. However, the public training does not necessarily alter top managers' perspectives of responsibility but more likely sharpens and reshapes the perception of responsibility.

The comparison demonstrates the significant role of top managers' attitudes to responsibility in both countries in shaping firms' perceptions and later on directing firms' behaviours. The bottom-up approach initiates, mobilises and enhances the awareness of responsibility, embedding responsibility values and culture in firms.

7.4.2 Culture, training and behaviours of the business

An additional external factor that influences top managers attitudinal input is public training in the UK. The UK has witnessed the prevalence of public training of RRI in the SynBio sector; this agenda has been advocated and pushed, sometimes jointly, by several main government departments, funding agencies, industrial organisations and civil societies. The UK RRI public training often targets not only researchers but also people in the industrial sector, where profound innovation decisions are made for responsibility and commercialisation. In comparison to the Chinese situation where the SynBio societal responsibility agenda has yet to be prevalent among researchers and industrial people, UK RRI public training hold a superior position where the training agenda presents not only a larger number of workshops and but also deeper interdisciplinary interaction.

Public training can be seen as one of most significant elements in influencing UK companies' perspectives on responsibility, which consists of workshops and seminars organised by research institutions, government departments and funding bodies. In contrast to the Chinese government's input on implementing responsibility activities, the UK government seems devoted to embedding a sustainable, responsible culture and mindset in both research and industrial settings.

The comparison result demonstrates the significant role of external forces in forming firms' perceptions on responsibility. The top-down approach enhances and institutionalises the norms of responsibility and science ethics, embedding awareness and responsibility values into top managers' cognitive competence, which later can later be transformed into business or industrial culture.

The evidence does not imply that the top-down approach alters top managers' attitudes to responsibility but rather enhances and sharpens the top managers' favourable attitudes and existing cognitive competence. While some UK top managers believe that the top-down approach provided a new way of perceiving responsibility, and thereby sharpened their comprehension and cognitive competence, top managers in one UK case argued that exposure to training did not change their indifferent perspectives towards RRI. Thus, it indicates that top managers' attitudes lay the foundation through which the top-down approach enables enhancing and sharpening cognitive competence.

Training top managers, especially their attitudes to responsibility, is therefore highly suggested and recommended to policymakers, which will be fully discussed in the next section.

7.5 Summary

This section summarises the research findings and aforementioned analysis, which enriches the theory of responsibility research and innovation in industry settings with original evidence and contributions on practising responsible research and innovation through the mediating role of top managers with a mixture of policy instruments.

Three main motivations of firms' responsibility activities were explicitly identified in the previous empirical chapters, which include top managers' inputs, business strategic inputs and public trainings initiated by governments or equivalent agencies. Companies in China and the UK are motivated by different sets of elements to mobilise and implement responsibility activities; while Chinese companies are mainly motivated by internal forces—top managers' attitudinal inputs and strategic inputs, UK companies are mostly motivated by a mixture of external and internal forces, namely, top managers' attitudinal inputs and

public training. The following chart (Chart 5.1) summarises the different motivations of firms' responsibility activities between the two countries.

Internal forces, as argued before, include top managers' attitudinal inputs and strategic inputs. Strategic inputs are management strategies deployed by top managers in trying to respond to external factors, such as the factors of market and value chain. Internal forces mean that the motivations to perform responsibility activities come from within firms. Through this comparison study, the significant role of top managers in initiating and implementing responsibility activities with their attitudinal inputs and strategic inputs stands out. Top managers import values, beliefs as well their strategy deployment into firms, potentially embedding some into firms' culture. Hence, top managers are considered the key players of the internal force.

External forces, as argued previously, include policies and institutionalisation instruments, such as seminars, workshops, training and open information. External forces mean that the motivations are stirred by external players, mainly governments and equivalent agencies, outside firms. Through this comparison study, the significant role of institutionalisation instruments in stirring up and shaping top managers' perspectives on responsibility, thereby shaping firms' perceptions and behaviours to responsibility and responsibility activities stands out. The institutionalisation instruments enable the values of responsibility to be embedded into the culture in SynBio communities. Governments and equivalent agencies are considered the key players of external forces.

Importantly, institutionalisation instruments influence firms' perceptions and behaviours through the role of top managers. This means that top managers' perspectives lay a foundation of firms' attitudes to responsibility and the configuration of responsibility activities. Hence, although patterns can be observed in the two countries in which Chinese firms differ from the UK firms in perceiving and implementing responsibility activities, owing to institutionalisation instruments, individual firms have their own characteristics when perceiving responsibility and implementing responsibility activities because of the personal characteristics of individual top managers.

Both countries are seeing firms adopting a mixture of motivations when performing responsibility activities; each firm can adopt various motivations depending on their top managers' perspectives and the existing external forces. While Chinese firms' motivations for performing responsibility activities mainly come from internal forces—top managers' favourable attitudes to responsibility and strategic inputs, UK firms are observed to be motivated by both internal forces and external forces. Although this study analyses and emphasises the aforementioned motivations, this is not to imply that firms are merely motivated by these motivations; rather, it is argued that these motivations stand out through the data as the main motivations. For instance, strategic input is one of the main motivations for Chinese firms to perform responsibility activities, which does not imply that the UK firms do not take strategic inputs into account, but rather that this motivation does not stand out as the main one in the UK SynBio industrial setting.

As a result, when considering why firms perform responsibility activities, both external and internal forces should be taken into account, and when considering how to mobilise firms to perform responsibility activities, the role of top managers must not be overlooked.

The two comparison studies additionally indicate the significant role of governance and top managers in raising the awareness of responsibility, shaping perceptions, and thereby guiding the implementation of responsibility activities. Although external forces impact sufficiently on firms' perceptions of responsibility and responsibility behaviours, top managers contribute the major inputs to laying the attitudinal foundation and guiding and determining the configuration of responsibility activities in accordance with business strategies. Hence, external forces such as policies and institutionalisation instruments are not adequate to embed the ideology of responsibility into industrial settings. A bottom-up approach should also be considered to shape the values, mindsets and culture.

Although the concept of RRI does not take place in the UK's government policies, the notion is addressed and embedded in the strategic guidance of the development of the SynBio sector, industrial documents, statements as well as SynBio funding schemes (See Chapter 4). However, there are cases indicating that neither the mixture of polices nor the top managers or other factors influenced their perceptions of responsibility in innovation. The

following section analyses this from a much broader societal perspective to understand the complex concept of responsibility in emerging technology sectors (in industrial settings).

Collaborative responsibility in a divided society

Although the early definition of responsible research and innovation as a code of "(ethical) acceptability, sustainability and societal desirability" (Schuurbiers, 2011, p. 9) was criticised by the argument that there could be no consolidated normative across different cultures, and the much broader definitions of "creating high-quality science that is more in the public interest" (RRI Tool, 2018) or "responsible innovation means taking care of the future through collective stewardship of science and innovation in the present" (Stilgoe et al., 2013) were promoted, the essence of the concept was rooted in some key words: society, needs of society, society's future, code of good conduct. While it is difficult to assert what is "good" and what is "not good", it is even harder to define the so-called society. Various scholars argue what society is, for instance, Horton and Hunt: "A society is a relatively independent, self-perpetuating human group which occupies a territory, shares a culture and has most of its associations within group"; Maclver and Page: "society is a system of usages and procedures, authority and mutual aid, of many groupings and divisions, of human behaviour and of liberties"; Giddings: "society is the union itself, the organisation, the sum of formal relations in which associating individuals are bound together''. The essence of the definition is that society consists of groups of people who are bound together by certain similarities. It is therefore questionable to refer to RRI in absolute terms such as "societal desirability" or "public's interests", which creates confusion around RRI and adds complexity.

Owen, in his book *Responsible Innovation* (Stilgoe et al., 2013), argued that the notion of taking responsibility should be seen as both quasi-parental and collectively political. He emphasised that a person has a limited kind of responsibility and a society collectively shares responsibility regardless of their political views on the contribution of technology. It is argued that the concept of quasi-parental responsible innovation means that no one should single-handedly determine the trajectories of innovation, but the individuals who compose the sector or the group mutually share responsibility for the consequences. It is

argued that a person, in the concept of collaboratively political responsibility, sometimes takes on the guilt and responsibility even if she/he did not take the actions her/himself because of the behaviour of a group of which she/he is a part. This argument emphasises the essence of RRI, which is that "all the stakeholders hold mutual collective responsibility".

However, the notion of quasi-parental and collectively political responsible innovation fails to maintain another aspect of responsible innovation, that the anticipated contribution of technology and innovation can be easily jeopardised when even one individual of the group fails to meet the normal or political requirement and standardisation; therefore, a common ground must be reached, both domestically and internationally, in order to establish standardisation.

For instance, a country's military force could develop frontier defensive SynBio weaponry which could also be used for wrongful civilian attacks; the nature of military work requires confidentiality, which means it is challenging for such SynBio research and innovation to be governed under the same regulations as the civil industrial sector and it is challenging for such SynBio research and innovation to be assessed by the same sustainable or humanitarian standardisation as the civil industrial sector. As such, the goal of responsible research and innovation cannot be achieved at all when it is not achieved collectively. Likewise, the goal of responsible research and innovation should be achieved collectively and internationally.

This research has demonstrated how a mixture of non-standardised principles and policies influences firms' responsibility perceptions and behaviours, mediating the cognitive filter of top managers. As society consists of various groups holding different political opinions about responsibility, social needs and the fundamental relationship between science and the society, and the quasi-parental, collectively political nature of RRI requires a set of standardised principles in order to guide its implementations and practices, a common ground among stakeholders, domestically and internationally, should be reached before the narratives of RRI can be implemented, especially in industrial settings.

8. Conclusions

8.1 Introduction

This research investigates and compares the commercialisation and responsibility activities of the synthetic biology sectors in the UK and China. It aims to understand the de facto RRI/responsibility activities in the industrial sector by examining *why* and *how* SynBio companies perform responsibility activities. Additionally, it sheds light on how innovation systems differ in shaping responsibility activities in industrial settings. It addresses a gap in the literature about perceiving responsibility activities from a bottom-up perspective and a cross-nation perspective. The motivations and approaches by which firms perform responsibility activities and their perceptions of responsibility are investigated in order to answer the research questions.

The proposition is to have an exploration and understanding of how companies in different jurisdiction systems address societal challenges and embed responsible innovation in synthetic biology commercialisation. The main contribution is bridging the literature by investigating at the management level, as well as by comparing different jurisdictions. This study provides an in-depth analysis of *why* and *how* firms conduct responsibility activities in the SynBio sectors of the UK and China. The results indicate the significance of governments and top managers in mobilising and guiding the implementation of responsibly activities. In addition, it emphasises the significant role of training in the innovation system, both on the national level and on the firm level, in raising awareness of responsibility and facilitating implementation of responsibility activities.

The original contribution of this thesis is that it offers a previously under-explored perspective on responsibly activities, addressing the different innovation systems in shaping firms' responsibility behaviours and top managers' contributions in mobilising and guiding responsibility activities within industrial settings. Thus, it adds to the existing RRI literature viewing responsibility activities from a top-down approach, and specifically in research settings instead of industrial ones. This angle has rarely been explored by other researchers in this field before.

Additionally, the qualitative approach adopted by this study contributes a wealth of descriptive data and storytelling materials on firms' responsibility behaviours, by which responsibility activities can be comprehended in the explicit contexts, taking into account firms' macro external innovation ecosystems and micro internal environments. This in-depth approach also emphasises the significance of training on the national level and on the firm level in initiating and implementing responsibility activities, which has yet to be sufficiently addressed by the literature. Mainly qualitative methods were employed for this study. A total of 58 semi-structured interviews were conducted, including with policymakers, investors, social scientists, CEOs and CTOs of SynBio firms. The SynBio landscapes of both countries were presented based on "landscape stakeholder interviews". Semi-structured in-depth interviews were conducted to gain a deep understanding of responsible innovation and its practice in commercialisation in the synthetic biology industry. The data was collected from synthetic biology companies located across the two countries: the UK, and PR China.

These two countries were chosen as representative of various jurisdictions, innovation systems and public mentality. Additional data were collected through website analyses and the researcher's participation in relevant seminars organised in the UK and China.

This chapter starts by presenting the research model in order to understand the elements influencing firms' perceptions on responsibility and implementing responsibility activities. It then revisits the research questions to refine the research framework. Then it discusses the theoretical and practical contributions, including, but not limited to, the contributions to RRI in the industrial environment, in various innovation systems and the implications for policymakers, top managers and social scientists. The last two sections of this chapter highlight possible future research areas, research limitations as well as practical implications for policy and research.

The research framework enables evidence-based analysis of the research problem and helps define how traditional services take environmental action and adopt energy-efficient technologies and measures. It is used here to answer the research questions in light of the empirical findings.

In trying to explore how societal responsibility is perceived and how its practise is implemented within businesses in emerging innovation industries, this research investigates how businesses perform responsibility activities and compares the UK and China in order to investigate how two different innovation systems influence their businesses with regard to responsibility innovation and research.

8.2 Revisiting the research questions

RQ1: How do companies in the emerging technology sector perceive societal responsibility?

This research not only examined and analysed how firms in the UK in China perceive responsibility and responsibility activities but further investigated the core elements shaping these perspectives.

The empirical findings identify several core motivations contributing to shaping firms' perceptions of responsibility and responsibility activities. Findings also confirm the proposition that government policies can significantly influence firms' perceptions and guide their behaviours. These core motivations are summarised in Table 2 below.

Motivation	Motivation	Key elements	Found in
A. **Push force (External)**	Public training	Public reports	The UK
		Public workshops and seminars	The UK
		iGEM ethical training	The UK, China
	Funding	--	The UK
B. **Pull force** **(Internal)**	Strategic inputs	Understand perspectives of the public (especially customers) and how it impacts their main business	The UK, China
	Inputs from management team	From CEO/CTO/key staff;	The UK, China
		Personality; personal belief; previous life experience	

Table 2. Core motivations contributing to shaping firms' perceptions of responsibility and responsibility activities *(Source: Author)*

Motivation patterns

This research identifies three main underlying motivations by which firms initiate and implement responsibility activities: push forces leveraged by the government, top manager's attitudinal input and firms' strategic input. Strategic inputs and top managers' attitudinal inputs are the main motivations found among Chinese firms whereas top managers' attitudinal inputs and public trainings are the main motivations found among the UK firms. This said, firms in both countries were observed to have a mixture of motivations, depending on how they prioritise business goals.

This research also shows the differences in how firms perceive responsibility in the two innovation systems. While firms in China, where institutionalisation of responsibility is not largely evidenced, perceive responsibility mostly in accordance with the conception of CSR

where “contributing back to the society and community” is the main notion, firms in the UK interpret responsibility in a manner that is often aligned to segments of RRI narratives, where elements of “awareness and inclusiveness” are heavily addressed. However, not all of the UK firms perceive responsibility in this fashion; some view responsibility in close association with the concept of CSR.

These two findings confirm the proposition that the UK and China differ in shaping responsibility perceptions and behaviours in industrial settings, where the UK has an institutionally established RRI framework and China does not.

In comparison to China, where firms build their perceptions of responsibility around CSR, the UK firms construe responsibility within the scope of RRI narratives. The phenomenon may or may not result directly from the institutionalisation of RRI in the UK, but certainly cannot occur without the influence of this process. It is evident that most UK top managers’ attitudes are derived from RRI or science ethics workshops, seminars, other public trainings or open online resources initiated by the UK government or equivalent governmental departments. The significant role of government in embedding responsibility culture in firms and shaping their perceptions stands out greatly when comparing UK firms’ perspectives with Chinese perspectives. In China where RRI narratives are yet to become widespread, the conception of CSR is observed to be prevalent among firms, whereas in UK where RRI narratives are blended into industrial and research agendas, it is otherwise.

Another aspect that this research indicates is that there is an international influence on shaping firms’ perceptions of responsibility, since some firms, especially the UK ones, are derived from iGEM competition. This influence may grow rapidly with more teams participating and more teams transferring their iGEM research into enterprises.

RQ2: How do companies in emerging technology sector practise responsibility activities?

This research examined how SynBio companies in the UK and China practise responsibility activities in seeking potential patterns of firms' responsibility behaviours.

Firstly, this research identified two configurations of firms' responsibility activities: embedded activities and side activities. They are identified in this research based on the extent of their direct engagement and involvement with decision-making processes of the main business activities, which, mostly refers to "development, manufacture and sale of products and services" (BBSRC, 2015; GOV.UK, 2014).

Embedded activities are, as the name suggests, activities embedded in firms' main business decision-making processes. The main indicator of an embedded activity is that it has a direct effect on the main business activities. Embedded activities have the properties of "awareness, inclusiveness and reflection", where "awareness" refers to the notion that science and innovations occur in a wider ecosystem where multiple aspects mutually impact on each other. These elements, such as innovation, politics, regulation, societal institutions, environment, and public perception (social behaviours and psychology) inevitably impact on each other. Inclusiveness and reflection include the awareness and actions of firms in embracing various stakeholders in the decision-making process and then output innovation decisions that align with the benefits to society.

Side activities are responsibility activities not involved in the main business decision-making processes. The evidence shows that they have three necessary but not sufficient properties: "transferability" (same model of activities can be applied at different firms), "repetitiveness" (models of activities can be and are likely to be repetitively conducted in firms) and "replaceability" (main business of firms will not be directly affected by the replacement of activities).

The means by which this research categorises responsibility activities can facilitate our understanding of firms' responsibility behaviours. Firstly, it outlines the activities' degree of involvement in business decision-making processes, implying the absence or presence of "reflection". Secondly, it emphasises the role of "reflection" in addition to "awareness" and "inclusiveness" in responsibility activities, especially in the context of developing new

R&D projects. Lastly, it distinguishes responsibility activities in accordance with their goals, so that a science festival outreach event that aims at raising the public's interest in specific innovation technology is just as much appreciated as a firm's ethical committee rejecting an R&D proposal for its environmental risks, without expecting solid reflective feedback from the general public on the event.

For instance, two firms may conduct engagement activities out of different aims—with one trying to comprehend the complex picture of risk analysis and life-cycle analysis and another reaching towards the goal of public education. Both activities are conducted out of accountability and responsibility; both are conducted in the form of engagement. However, the former activity would be perceived as failed if "reflection" was absent, whereas the latter one would be considered as achieved.

Secondly, just like firms' perceptions of responsibility, both the UK and China have a mixture of behaviours in practising responsibility activities regarding the configuration and frequency; every firm also has its individual characteristics. Evidence shows that firms practise responsibility activities in accordance with firms' perceptions of responsibility and responsibility activities. Regardless of their business nature (B2C, B2B) or size, firms that have a favourable attitude to responsibility or responsibility activities demonstrate sufficient responsibility activities.

RQ3: How do innovation systems differ in influencing the societal responsibility practice?

Thirdly, this research analyses how innovation systems differ in influencing the societal responsibility practice. Since the UK government and other civil organisations advocate RRI, these firms have a deeper comprehension of responsibility, especially on various social aspects of research, production and final products.

(1) In contrast with Chinese firms, UK firms seem to have a deep comprehension of the societal aspect of science and innovation by taking into consideration more social aspects of research, production and final products whereas Chinese firms are more likely to consider these elements as a whole. Top managers of the UK firms investigated were observed to have a favourable attitude towards responsibility,

tended to be more outspoken, enthusiastic and insightful when discussing organisational responsibility and social concerns of synthetic biology.

(2) The UK firms were mostly observed to perform embedded activities, with a few side activities observed such as science festivals and public education, which share some similarities with the side activities adopted by the Chinese firms.

The UK government's public education/training of RRI has a significant impact on firms' perceptions and practice of responsibilities.

8.3 Contributions to knowledge

(1) The main contribution of this research is bridging the literature by investigating and exploring the industrial perspective of responsibility in the emerging technology sector.

(2) The research also contributes with an exploration and understanding of how companies in different innovation ecosystems address societal challenges and embed responsible innovation in synthetic biology commercialisation.

(3) The mediating role of top managers is explored and discussed in this research, bridging the gap of the literature where there is a lack of investigation on responsible innovation from approaches other than top-down.

8.4 Practical implications

The implications are drawn from the results of this study, which focus on the significant roles of policymakers and firms, especially top managers. The following section summarises the implications, which include:

For policymakers:

(1) Set up industrial examples

Policymakers can demonstrate industrial examples (e.g. successful cases of the internal ethics committee) of how various firms conduct responsibility activities, which can function as a basic standing point for firms to gain awareness and sharpen their comprehension of

responsibility. Firms can thereby visualise the abstract conceptualisation of responsibility, especially in regard to what RRI can refer to in practical settings. For example, policymakers can present the idea of an internal ethical committee to the SynBio industry, illustrating its incentives, thinking processes, and practices.

(2) Enhance push forces

Institutionalisation, especially public training, should be enhanced by policymakers in order to raise awareness of responsibility and embed the ideology as part of the industrial culture. The institutionalisation of responsibility will not succeed until it is fully embedded in the firms' culture as firms' values and beliefs. To achieve this, training for top managers must be emphasised. Public training for firms' top managers should be available and compulsory in order to address the accountability and responsibility in the industrial setting, where the training content should be designed in such a way that it raises awareness of the responsibility and social aspects of innovation and it sharpens the comprehension of the practices of inclusiveness and reflections. The training may alter top managers' attitudes towards responsibility and embed the awareness of responsibility into their personal beliefs. By adopting this top-down approach to training, it enables a revolutionary mindset shaped from the bottom up.

8.5 Limitations and further research

This study is, like any other study, subject to limitations. This section reflects on three main limitations of this research, which leads to suggestions for future research.

Interview as method

Interviewing, as a research instrument, has many drawbacks. Trying to obtain data in a direct manner from detailed stories is difficult. This section discusses two main inherent drawbacks of adopting interviewing as the main data collection method for research.

Firstly, interviewing suffers from response bias, where the verbal content that interviewees offer can be shaped, to some degree, by the questions they are asked and by the approach with which questions are asked. In some situations, interviewees manipulate the answers

to meet the expectations that they believe the interviewer has. Researchers may easily overlook subtle details, such as facial expressions, body language, linguistic communication, social etiquette and wording, which can affect the direction of conversations, and hence influence the results of interviews.

Although this research adopts a systematic approach to increase the reliability and validity of data collected through interviews by "avoiding asking leading questions; taking notes not just depending on tape recorders; conducting a pilot interview; giving the interviewee a chance to sum up and clarify the points they have made and compensating interviewing with associated observations" (Creswell, 2009, p.153), it cannot completely eliminate this inherent drawback of the interviewing method.

Secondly, interviewing suffers from self-report bias. Relying on direct data collated from verbal resources, all interviews are limited by the fact that they can rarely be independently verified. Needless to say, interviewees, as human beings, are limited not only by their own individual cognitive bias such as elective information, attribution, telescoping bias and so on, but also by the manners and approaches in which they provide the data, which could be influenced by their communication skills, linguistic ability, comprehension and the environment in which they are reporting answers. Consequently, the best interviewing can never be perfect. Despite the additional observations conducted to compensate for the interviews in this research, where further non-verbal data, such as data collected from reviewing firms' documents, visiting firms and attending meetings with firms' decision makers, limitations derived from self-report bias cannot be eliminated.

Another concern associated with self-report data is that one can only interview those who are available to be interviewed. Self-report data relies much on volunteering, which could result in survival bias where conclusions are drawn from only upon one or a few aspects or data groups. Although this research captures two sides, with data collected from both firms that had favourable attitudes towards responsibility and firms that did not, one must bear in mind the possibility of other interpretations.

Some other research limitations include, but are not limited to: 1) SynBio is an emerging sector where uncertainties exist and changes can occur rapidly; the landscapes of commercialisation and policies may vary, even within a short period of time owing to its continuous evolvement. This research, therefore, should be considered open-ended rather than conclusive, which adds the exploration of commercialisation and firms' responsibility activities to existing research; 2) Although this research explores the state of the art of commercialisation and responsibility activities in the SynBio sector, it merely examines and compares it in two countries, which just touches the surface of the topic considering the vastness of the subject; 3) Additionally, political factors in emerging technologies could be highly unpredictable; particularly in this case, Trump's presidency and Xi's constitutional amendment hinder the possibility of accurate predictions. Hence, this study may not have been able to capture some issues that could become major concerns later on.

Lastly, the RRI conception and its practice in the industrial setting are still relatively new and ambiguous in the literature. This study attempts to grasp the state of the art of responsibility (RRI) activities in industrial settings in order to bridge the gaps. For example, when studying public perspectives of GM, some studies emphasised elements such as educational level, gender, age and product types, concluding with correlations between these elements and how they perceive GM products. This analysis fundamentally overlooked the factor of human psychology and human behaviours, under-analysing the radical element of "what do customers expect from the product". The correlation between "effective, affordable medicine is made from GM technology", "people express less concern in this type of product" can be explained by the fact that customers usually look for effectiveness apart from affordable prices in medicines, especially for severe diseases. Another example is in the concept of RRI, when considering "putting the development of science in alignment with the values and needs of society", it overlooks the fact that society consists of various groups with distinctive values and needs. One should not simply assume society desires the same values or needs; even on the fundamental topic of world peace, it can be argued and evidenced that a certain group of people benefit from wars and that they do not value world peace at all. Therefore, concerns arise of whose values and needs RRI represents?

Generalisation of this research

Although the results of this research are based on the data collected solely in the SynBio sector in the UK and China, it could potentially be applied to a wider range of high-tech sectors in similar settings, which could include SynBio in other ecosystems or other emerging technology sectors, such as AI, robotics, and Internet of Things (IoT). Emerging technology fields share certain similar characteristics, such as uncertainty in future developments, immaturity in innovation policies, lack of relevant regulations etc. Implementing new innovation policies requires a large amount of resources under such circumstances, with particular challenges in implementing innovation policies in individual company's working environments. With the mediating role of top managers, as this research concludes, public innovation policies can potentially be embedded effectively into companies' cultures and activities.

Furthermore, as this research articulates, top managers mediate between macro innovation systems and micro working culture and activities of companies in order to employ strategies of responsibility. These findings could be generalised into areas other than emerging technology fields, such as banking (e.g. Fintech) and accounting.

Future research

Future research is recommended in the following section. Firstly, future research can consider quantitative statistical analysis to examine to what extent companies are initiating responsible innovation strategies and activities. Multiple case studies and qualitative research provides a broad landscape perspective but quantitative methods could make the research more rigorous, which is the main purpose of case studies (Yin, 2003).

Secondly, given that the research aimed at exploring how businesses in the UK and China implement responsibility policies and conduct activities in the emerging technology industry, SynBio firms were selected regardless of the size, developing status and business models since the total number of SynBio firms were limited in both the UK and China. Hence, they cannot represent the whole picture of how companies implement responsibility policies in the UK nor China. As the research findings demonstrate, individual

companies are not representative of their countries or the industry, particularly when top managers allow personal input when implementing new policies. Future research could investigate a larger number of companies since the SynBio industry has developed rapidly to verify the findings of this research and to gain a deeper understanding of responsible innovation in the UK and China.

Thirdly, the rationale for this research could be extended to other emerging technology industries and a broader range of countries. A similar analysis could be applied in other emerging technology areas, such as AI, robotics, and IoT to verify the generalisation of this research. Additionally, US companies should be investigated in order to gain a deeper understanding of responsible innovation in the SynBio industry since the USA is one of the leading countries apart from the UK and China. Although these three countries have played significant role in the sector so far, the number of SynBio companies are developing rapidly in other geographic areas. Extending the research to other countries could therefore benefit responsible innovation in the SynBio field in general.

In conclusion, this research has shown the significant role of top managers in mediating innovation policies and incorporating these into companies' cultures and activities. In contrast with the top-down approach, which has been investigated in many previous studies, little attention has been paid to the bottom-up approach. Hence, more research should be encouraged to explore this area. Future researchers could consider building qualitative research frameworks to investigate how responsible innovation is embedded and incorporated into individual business environments from the bottom up. Additionally, the mediating role of top managers needs future research with a larger sample to validate it in other countries.

APPENDIX A

Empirical Research Interview List

U.K. Landscape Interview List		
Code.	Institution:	Description:
CBLI1	UK Synthetic Biology Leadership Council	Co-chairman./Policy Maker
CBLI 2	ICL Centre	ICL--Accelerator /Prof of Synthetic Biology
CBLI 3	Cambridge Consulting	Industrial Consultant
CBLI 4	ICL Centre	ICL-- Accelerator/Prof of Synthetic Biology
CBLI 5	Open Plant Centre	Public Relations
CBLI 6	University of Edinburgh and the Open University	Innogen Institute / Prof of Social Scientist
CBLI 7	MIB	Project Director / Synthetic Biology Scientist
CBLI 8	MIB	Manager/ Synthetic Biology Scientist
CBLI 9	MIB	Manager / Synthetic Biology Scientist
CBLI 10	UoM and MMU	Prof of Social Scientist
CBLI 11	Civil Society-NGO	Director
CBLI 12	Open Plant Centre (Open Innovation Projects of Synbio)	Open Innovation Manager of Synbio
CBLI 13	Cambridge Centre	Social Scientist /Synbio Innovation Policy Researcher
CBLI 14	Bristol Centre Investing/Innovation management	Innovation Manager / Synthetic Biology Scientist
CBLI 15	MIB open day events with the general public (Mostly A level students) 2017	

U.K. Company Interview Lists		
Code.	Institution:	Description:
CBCI15	CBC 1	CEO
CBCI 16	CBC 1	CTO
CBCI 17	CBC2	CEO
CBCI 18	CBC3	CTO
CBCI 19	CBC4	Head of Strain Development
CBCI 20	CBC4	Head of Strain Development
CBCI 21	CBC5	CEO
CBCI 22	CBC5	CTO
CBCI 23	CBC6	Business Development Manager
CBCI 24	CBC 1	CEO
CBCI 23	CBC 9	Principal Scientific Investigator
CBCI 26	CBC 8	R&D Director
CBCI 27	CBC 7	CEO

Chinese Landscape Interview Lists		
Code	Institution:	Description:
CNLI1	CAS	Prof of Social Science /Innovation Policy Maker
CNLI2	Tsinghua University	Prof of Synthetic Biology
CNLI3	University of Tianjin	Prof of Synthetic Biology
CNLI4	CAS	Prof of Social Science /Innovation Policy Maker
CNLI5	University of Science and Technology of China	Prof of Synthetic Biology
CNLI6	University of Science and Technology of China	Prof of Synthetic Biology
CNLI7	Suzhou Industrial Park	Head of Suzhou Industrial Park
CNLI8-CNI15: 7 recordings of CN Synbio discussions and meetings with the local governments, with each lasts around 20 minutes to 1.5 hrs.		

China Company Interview Lists		
Code.	Institution (Company):	Description:
CNCI16	CNC1	CTO
CNCI 17	CNC1	CTO
CNCI 18	CNC1	Leader of iGEM team sponsored by CNC1
CNCI 19	CNC2	CEO & CTO
CNCI 20	CNC3	CEO & Marketing Director
CNCI 21	CNC4	Head of Public Relations
CNCI 22	CNC4	Head of Public Relations
CNCI 23	CNC5	CEO
CNCI 24	CNC5	CTO
CNCI 25	CNC6	CEO & CTO
CNCI 26	CNC7	CTO
CNCI 19	CNC8	CTO
CNCI 20	CNC9	Head of Synbio R&D
CNCI 27	CNC9	Ethical Committee
CNCI 28	CNC9	College--High School
CNCI 29	CNC9	College--Uni
CNCI 30	CNC9	Ethical Committee
CNCI 31	CNC9	Ethical Committee

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