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Policy Makers' Influence on the Emergence of a New Scientific Discipline: The Case of Nanotechnology in Ireland

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Policy Makers' Influence on the Emergence of a New Scientific Discipline:

The Case of Nanotechnology in Ireland

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GENERAL ABSTRACT

Science has undergone tremendous changes since World War II with the blurring of boundaries between science, government, and industry, as well as the so-called convergence of scientific disciplines. Nanotechnology is an illustrative example of this phenomenon. Boundaries between all these spheres are challenged, renegotiated, and reshaped under the influence of the multiple actors involved. I question here the extent to which nanoscience and nanotechnology (N&N) are emerging as a new scientific discipline under the influence of science and technology policies. With the study of N&N in Ireland from the late 1990s onwards, a focus is placed on both the macro-meso and meso-micro levels of analysis. Through a comparative case study research design of six research teams, I describe that policy makers have, to a certain extent, restructured the physical boundaries of science to make them conform to the nanotechnology logic, whereas the social and mental boundaries are still ruled by an established paradigm logic. This is confirmed at the meso-micro level with the identification of the barriers that scientists with diverse backgrounds face in a multidisciplinary laboratory. Thus, nanotechnology as a general purpose technology has challenged and renewed our theoretical conceptions of technology management by affording possibilities for both radical and incremental innovations. Moreover, even though policy makers are more involved in the scientific activity, they have a limited impact on it by not being able to steer the cognitive structure of science. Boundaries, in these types of organisations, instead of being blurred, are becoming ever more complex.

DECLARATION

I certify that this thesis, which I now submit for examination for the award of Doctor of Philosophy, is entirely my own work and has not been taken from the work of others, save and to the extent that such work has been cited and acknowledged within the text of my work.

This thesis was prepared according to the regulations for postgraduate study by research of the Dublin Institute of Technology and has not been submitted in whole or in part for another award in any Institute.

The work reported on in this thesis conforms to the principles and requirements of the Institute's guidelines for ethics in research.

Signature ________________________________ Date_________________________

Candidate

A mon père, cet homme simple et discret qui m’a toujours encouragé et ce, peu importe la route empruntée.

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LIST OF ABBREVIATIONS

BM: Business model

EPA: Environmental Protection Agency

FP6: Sixth European Framework Programme

FP7: Seventh European Framework Programme

GPT: General purpose technology

IRCSET: Irish Research Council for Science, Engineering and Technology

KET: Key enabling technology

N&N: Nanoscience and nanotechnology

PI: Principal investigator

PRTLI: Programme for Research in Third-Level Institutions

SFI: Science Foundation Ireland

STP: Science and technology policy

WOS: Thomson Reuters Web of Science

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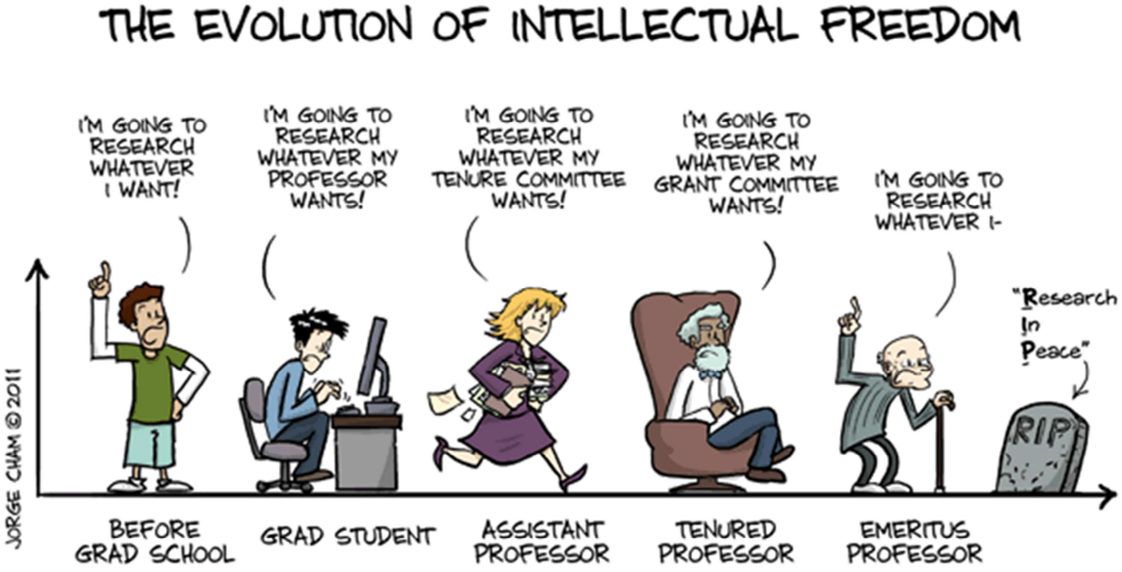

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Chapter 1.

Defining the empirical, theoretical, and methodological bases of the study

1.1 INTRODUCTION

In industrialised countries, nanotechnology has challenged the spheres of science, politics, and industry. It crosses the established disciplines of physics, chemistry, and biology, and can be found in a number of applications in multiple sectors from electronics to medicine. Nanotechnology has been promoted by policy makers in order to foster its development. However, the dynamics of emergence of new scientific disciplines under the science and technology political pressures are still poorly understood. They are difficult to grasp as both the macro and micro levels must be considered in order to understand how the physical (infrastructures), social (identity), and mental (cognitive structure) boundaries are reshaped between the different actors. Institutional logics bring a suitable lens for this study as they allow within the same theoretical frame to consider the three types of boundaries of the various actors involved in the phases of field emergence, how they evolve, change and are reshaped.

1.2 EMPIRICAL INSIGHTS OF THE STUDY

Since the end of World War II, the role of science for society has been a major issue for industrial countries and, in times of crisis, this debate is even more topical as science is one of the main drivers for innovation. Building a knowledge-based economy implies the articulation of and the coherence between policies, research and education, and the transfer of technology and knowledge to the industry. The balance between the independence of the scientific sphere from powerful actors, such as government or industry, is a thin line to find but central to all scientific and technology policies at both national and supra-national levels (Whitley, 1984, 2007).

Nanotechnology is the last major technology of the 20th century and has triggered attention from policy makers, scientists, and industry. It originated from the Greek word meaning ‘dwarf’ and refers to the scale of 10^{-9}, a nanometre being a billionth of a meter. In science and technology, it deals with the manipulation and control of the matter at the atomic scale. In his now famous talk ‘There’s plenty of room at the bottom’, Richard Feynman (1960) expressed the possibility – more a theoretical possibility at the time – to write the entire *Encyclopaedia Brittanica* on the head of a pin. In 1974, Norio Taniguchi was the first to coin the term ‘nano-technology’ to talk about thin film at the nanometre range. Things at the nanoscale are already present in Nature. The classic example is the gecko lizard that is able to climb and to cling on any surfaces thanks to 200nm hairs under its feet. By using the term technology, I am referring to the manmade artefacts.

Nanotechnology is said to cross multiple scientific disciplines and industrial sectors and to make them converge. High expectations are related to this technology and industrial countries have set programmes to foster its development. In 2001, The U.S. government started the National Nanotechnology Initiative and has set the pace for its development in other countries. In Europe, nanotechnology has become an independent scheme within the *Sixth* (from 2002 to 2006) and *Seventh* (from 2007 to 2013) *Framework Programmes*. The European Commission has produced several documents to identify the possible benefits of nanotechnology and to establish an action plan (European Commission, 2007, 2009, 2010). Funding, but also the coordination of nanotechnology research between European countries, have been an important challenge to European policies (European Commission, 2004).

Ireland – ranked sixth in the world for nanotechnology research – started to fund this technology in 2001, under the *Strategy for Science, Technology and Innovation*. Since then, different research centres dedicated to nanotechnology have emerged, such as the *Centre for Research on Adaptive Nanostructures and Nanodevices* hosted on the campus of Trinity College Dublin. Also, initiatives have been created like the *Integrated NanoScience Platform for Ireland* (INSPIRE) which groups together eight Irish and two Northern Irish universities around nanomaterials, nanoelectronics, nanophotonics, and bionanoscience. Moreover, to improve the coordination across the country, governmental agencies have created positions dedicated to nanotechnology. These agencies cover advisory bodies to the government, in addition to funding agencies that provide financial resources for both basic and applied research.

The premises of this research were to observe (1) the extent to which conducting research within these nano-dedicated places would differ from ‘traditional’ research and (2) the emergence of a new scientific discipline. Although, diverse research streams inform how science evolves, divides up, emerges and sometimes disappears, nanotechnology in Ireland afforded an opportunity to make contemporaneous observations about scientists with diverse backgrounds finding a common interest and building a new community. Moreover, financial resources are an essential element to the emergence of a new science and nanotechnology were becoming more and more important to policy makers. In that sense, the premises of this research also included the extent to which a country like Ireland which started to develop its research capabilities in the late 1990s reassembles its assets to be visible for researching nanotechnology at the international level and supports the emergence of a new scientific community. These points of entry triggered interest from policy makers as they were interested to have more information from scientists given that their actions on nanotechnology were mainly bottom-up. Scientists benefited from a certain freedom one the one hand, to conduct the research they considered relevant and one the other hand, to follow the research avenues both established by the scientific community and driven by societal and economic needs, such as improving materials, making better transistors, finding new drug delivery systems, testing the toxicity of nanomaterials, and so on.

On the scientific side, the way in which nanotechnology was defined was not clear. It was qualified from opening up new possibilities to a mere buzzword, from a totally novel way of conducting research to a relabeling of what has been going on for years. Moreover, even though calls for funding were mainly bottom-up, scientists acknowledged their dependence on external funding and, therefore, the influence on their research avenues. This dependence was revealed through the expression of tensions between the shift of funding from basic to applied research due to diminution of resources and the willingness to pursue research independently from resource constraints and political pressures. Scientists recognised that, in a time of crisis, emphasis is placed on applied research which has the greatest economic or social potential. These pieces of information led to adopt a deeper look at the policy side and how policy makers steer science in Ireland. Moreover, it looped back from scientists to policy makers and underlined the resistance that the former community can express over the later.

These empirical insights were interesting to follow for two main reasons. First, both spheres of science and policy were concerned, and interested, by this issue for their own purpose. Scientists, even though they acknowledge a certain dependence on external funding, were concerned about the evolution of their activity that is producing knowledge. On the other hand, policy makers expressed concerns about finding the fine line between steering science that would benefit society and letting scientists pursue their own directions which could have a potential future benefit; in other words, fulfilling current needs without jeopardising the future.

1.3 RELEVANCE OF THE STUDY

Tackling these issues is relevant for two main reasons. First of all, it enhances our understanding and knowledge about the dynamics of a central element of knowledge-based economies; that is, science and the extent to which it can be steered. Sociology of science has tackled the dynamics of science with seminal authors such as Merton (see Merton, 1957, 1968, 1973; Zuckermen & Merton, 1971), Latour (see Latour & Woolgar, 1979; Latour, 1987) and Knorr Cetina (1982, 1992, 1999), but also how science draws and maintains its boundaries (Gieryn, 1983, 1995, 1999) or emerges (Frickel & Gross, 2005; Jacobs & Frickel, 2009). However, these works tend to adopt an inner perspective (Granqvist & Laurila, 2011) and to hide – or at least underestimate – the role of external actors in the dynamics of science. A broader view must be considered to have a fairer picture.

A more macro understanding of the multiplicity of actors has been pictured by providing a broader view of the scientific activity (Whitley, 1984), producing new concepts such as Triple Helix (Leydesdorff & Etzkowitz, 1996, 1998a), emphasising the difference between a traditional way of conducting research with a more modern one (Gibbons et al., 1994; Nowotny, Scott, & Gibbons, 2003), or describing new forms of complementarities between the different actors involved (Bonaccorsi & Thoma, 2007; Bonaccorsi, 2008). However, these works adopt a macro view that tends to lose the sight of the trees for the forest. Organisation studies inherits from both streams of sociology and economics, and calls have been made to reconcile – even to melt – the micro and the macro levels to deepen both our comprehension of organisations' and fields' dynamics (Thornton, Ocasio, & Lounsbury, 2012; Thornton & Ocasio, 2008) but also of the complexity of the interrelationships between science and politics (Vermeulen, Büch, & Greenwood, 2007).

Then, as the rationales were empirically driven, this research is also grounded in the field's relevance (Vermeulen, 2005). For policy makers, the steering of science for economic and social purpose is of tremendous importance in the context of worldwide competition for knowledge acquisition and development. A small country like Ireland cannot invest in all areas of science, as financial resources are too limited. So, choices are made to be in line with the grand challenges that are defined at the European level, but they also must be feasible considering the financial resources and human capital. In that context, the impacts of political actions on science are essential. Indeed, policy makers must invest in areas that can provide the country with an as fast as possible return on investment, without compromising future research that necessitates long term investments.

1.4 TRANSFORMATION OF THE SCIENTIFIC ACTIVITY

1.4.1 Science as a human activity

Science is an organised collective action, structured around a set of fundamental core assumptions and practices, that aims at producing, transforming and diffusing knowledge (Frickel & Gross, 2005) and within which individuals struggle for scientific authority (Bourdieu, 1975; Gieryn, 1995). Different perspectives have been and are defended about what science is and, therefore, how it should be defined. This section aims at giving a brief introduction of science through two extreme views of the scientific activity: essentialism and constructivism. These views have roots in different disciplines, such as sociology, history, and philosophy of science. While essentialism (mainly Lakatos, Merton, and Popper) considers science as unique and with very well-defined boundaries, constructivism (mainly Callon, Feyerabend and Gieryn) sees it as any other human activity where boundaries are in constant negotiation. Although both views provide us with greater understanding of what science is, they do not imply the same considerations in terms of boundaries. This section does not mean to be exhaustive about the lenses through which science has been looked at; rather, it seeks to present a brief introduction about how this activity can be grasped.

1.4.1.1 Essentialism

Essentialism in science is an epistemological stream that considers scientific activity to be different from other cultural activities. Therefore, its unique, necessary and invariant qualities have to be identified in order to be able to explain its achievements. Although Merton's work explains more how science functions than how it evolves, it also gives the basic principles – the scientific ethos – under which scientists can be rewarded (Merton, 1968, 1988) or evaluated (Zuckermen & Merton, 1971). This scientific ethos is essential for science to be maintained. Merton (1942/1973) states that the scientific ethos of modern science is based on four institutional imperatives. First, scientists are ruled by *universalism*. This means that they must evaluate other scientists' contributions to knowledge with 'preestablished impersonal criteria' (p.270). In other words, a claim must not be biased by the personal or social attributes – nationality, gender, race or social class, and personal qualities – of the scientist who made it. In that sense, a scientist who is reviewing a manuscript must not be biased by the country, social condition, and so on of the author. Then, *communism* illustrates the common ownership of a theory or a law. Property is reduced to a minimum and rewards are limited to the esteem and recognition from the scientific community. This criterion makes the sharing of findings essential for science to progress and is at the heart of Isaac Newton's now famous saying: 'If I have seen further it is by standing on the shoulders of giants'. Next, *disinterestedness* is, for science, a 'basic institutional element' (Merton, 1942/1973: 275). To 'the accountability to their compeers' (p.276), Merton added that attempts for scientists to serve individual purposes – trying to develop cliques or pseudo-science – are limited by the peer-control system. Unlike in other professions, scientists are evaluated by peers and, therefore, trickery is less likely to occur. Finally, as, according to Merton, science is based on facts, personal judgement and beliefs must not interfere with empirical and logical criteria. *Organised scepticism* – the last institutional imperative which is interrelated with the others – is essential as the questionings and facts raised by scientific activity may come into conflict with data established by other institutions, such as religions or the state. By describing the scientific ethos through four institutional imperatives – or norms – by which science must stand, Merton states that this activity is, and must remain, independent and not influenced by other institutions.

Adopting also an essentialist position, Kuhn (1962/1970) gives a view on how science is actually performed and evolves. Although he has been criticised (Popper, 1970;

Toulmin, 1970; Watkins, 1970), Kuhn's (1962/1970) seminal work *The structure of scientific revolutions* and his definition of paradigm challenged the way in which science and its revolutions were considered. A paradigm provides scientists with guidance even when there is no theory (Masterman, 1970). Kuhn describes science as embedded in paradigms that channel scientists' way of thinking, legitimise their practices, and, in a more general way, rule the scientific activity. He defines these paradigms as a set of fundamental concepts and hypotheses, practices, methods and beliefs within which scientists practice – guided and oriented by these meta-rules – their scientific activity without sometimes even being able to define them precisely or to make them explicit. Within this frame, scientists constantly improve the discipline's paradigm by solving theoretical problems in order to have a better understanding of the natural world, an activity that Kuhn (1962/1970) labelled 'normal science'. When the current paradigm no longer provides scientists with improvable hypotheses – theoretical problems not being able to be solved with this frame – a small fringe of the scientific population can leave the community and try to solve these anomalies with new hypotheses, methods, etc. If this new frame is accepted by a large number of scientists, it will lead to a scientific revolution and to the constitution of a new paradigm. In Kuhn's conception of a scientific revolution, an established paradigm is challenged and, then, replaced by a more promising one. The concept of paradigm – fundamental hypotheses, practices, beliefs, and constant improvement – is complementary to Merton's scientific ethos as, while Merton (1942/1973) gives the rules to which scientists must conform, Kuhn (1962/1970) describes how science should actually be performed. This question was also central to Popper.

Popper (1959) stated that science has to be falsifiable and must be falsified. In other words, scientists must try to prove that their hypotheses are wrong instead of right in order to improve a research programme. Even though they differ on some points, ‘research programme’ (first introduced by Lakatos) and Kuhn’s ‘paradigm’ describe the general rules by which scientists are guided. If a hypothesis is proved right during the process of falsification, it is accepted or conserved and, conversely, if it is proved wrong, it has to be abandoned. By doing so, scientists continuously contribute to making a research programme closest to the laws of Nature. Lakatos (1970) enriched this view of science by arguing that the core hypotheses of a research programme are protected by a ‘shield’ of auxiliary hypotheses that will be exposed to the falsification process before the core hypotheses. For instance, when Einstein established the theory of relativity at the beginning of the 20th century, Newton’s theory had not been abandoned. Actually, it is still being used and improved. This view of improvement in science differs fundamentally from Kuhn’s version in the sense that, for Popper and Lakatos, a new science can emerge without wrecking another one. With his view of non-necessarily disruptive evolution of science, Popper (1970) fundamentally disagreed with Kuhn’s normal science, as it describes working within a frame without questioning it. Indeed, the main objective of scientists must be to find theories that always get closer to the truth by falsifying and increasing their content.

In order to grasp the complexity of scientific activity, Callon (1995) draws four models of science that each emphasises a particular aspect. The first two models echo an essentialist perspective of science. The first model, *science as rational knowledge model*, focuses on what makes science different from other activities. In this model, the role of scientists, the most important actors, is to produce statements. Technicians, manufacturers, and even society are not included in the scientific activity. Scientific production is a network of statements of which their classification and the characterisation of their relations are central. Callon defines the classification of statements and the characterisation of their relations as the difference between observational and theoretical statements and the different steps that are needed to go from the former to the latter; in other words, the transformation of an empirical observation or several empirical observations to a law, hypothesis or theory. Strong moral commitments and a reward system push scientists to produce more statements. Agreement is made through the proliferation of statements within a field of discussion – journals and conferences – where they are confronted and submitted to peers’ critique. This model relates to the institutional imperatives of Merton's (1942/1973) scientific ethos and the necessity of one frame and set of methods for all scientists within the same research programme. Callon (1995) expresses that this system is possible only if science is protected from society and other institutions to guarantee a free space for discussion.

The *competition* model is complementary to the first one in the sense that the validations of statements also depend on consensually agreed methods, but, in this case, certification of knowledge is the result of a process of competition. Scientists make statements by writing publications characterised by their novelty, originality and degree of generality. Again, scientists are the central actors and a distinction is made between them and laymen and laywomen, and technicians are reduced to the role of mere apparatus. Callon (1995) qualifies this model as a ‘Darwinian struggle in which [scientists] are both judges and litigants’ (p.37). Here, the free space of discussion is not as bounded as it is in the science as rational knowledge model. Even if the debates to reach an agreement about the statements occur between peers, exchanges with the non-scientific sphere, such as politics or society, are possible. Research programmes can, therefore, be influenced by industry or political decisions. Society and politics must support the boundaries between them and science in order to guarantee the sustainability of the system and the free space for discussion.

Whether it be Merton, Kuhn, Popper or Lakatos, and their respective dogmas, they consider science as being a peculiar activity independent from any other human activity, such as politics, economics or even what they would consider as non-scientific. Another epistemology, constructivism, considers science like any other human activity; that is, it is influenced by its context and history.

1.4.1.2 Constructivism

Feyerabend (1975) defends an anarchist view of science and is against any universal scientific method. This view runs radically counter to Merton, Popper, and Kuhn’s visions of science. Although Lakatos was largely inspired by Popper, Feyerabend considered the work on falsificationism (Lakatos, 1970) as ‘anarchism in disguise’. Instead, he considers that scientific laws, techniques, theories, and so on must be understood through their historical contexts; for instance, physics should not be separated from metaphysics and theology. Moreover, his ‘anything goes’ view illustrates the idea that a fixed method does not enable the exploration of every option and the discovery of facts that would not have been unveiled within a single frame. Even facts must be understood through their frame of discovery and historical context. Through his anarchist view of science, Feyerabend showed that phenomena can be looked at from different angles in order to make the different aspects emerge.

While the first two models described by Callon (1995) in the previous section are in line with the essentialism perspective, the *science as socio-cultural practice model* differs from them as, in this case, science is like any other human activity and, therefore, both social and cultural components are important. Knowledge and the production of facts are linked to the functioning of instruments and are local. Instruments are '*black boxes*' (Latour, 1987), which are the results of debates, controversies, and the reaching of a consensus between scientists. This is consistent with Feyerabend's (1975) vision of science, which integrates within it the social activity that surrounds the production of knowledge. Statements and practices are intertwined with experiments, protocols, and empirical observations. Moreover, all actors such as technicians, manufacturers, engineers, state agencies, media, and so on are included in the model and interactions between them are possible. Therefore, science is not a closed community; rather, it is seen as a network where different aspects of the network can impact. It is worth noticing the term 'community' is still used to characterise individuals that share the same culture and problems. Agreement is a consensus between social actors who are both inside and outside the community and, therefore, non-scientific actors can influence the production of knowledge. In this model, boundaries are constructed and negotiated, and may fluctuate over time.

The fourth and last model drawn by Callon (1995), *extended translation*, focuses on the proliferation of statements and their circulation through translation, and is based on an actor-network theory perspective. The latter refers to the operations that link technical devices, statements, and human beings. The objective of science is to produce statements that will be transformed through the translation chain to go from instruments and their outputs – inscription – to theoretical statements. The notion of actor disappears and is replaced by the one of 'actant': an 'entity with the ability to act' (Callon, 1995: 53). Within this frame, both instruments and individuals are actants. As statements are transformed from empirical observations to theoretical statements, the network is never static. Instead of agreement and disagreement on statement, Callon (1995) prefers alignment and dispersion of networks.

These introductive works – both essentialist and constructivist – give a first idea of what makes science different from another scientific domain, but also how to delineate it; in other words, its boundaries.

The constructivist perspective states that no demarcation between science and other activity is universally effective and that it is rather contingent, interest-driven, and drawn on inconsistent and ambiguous attributes (Gieryn, 1995). Based on critique levied by the defenders of constructivism against those of essentialism, Gieryn (1983) suggests a new approach to the construction of boundaries between science and other forms of knowledge production, religion, or forms of power, such as the state. Three types of boundary work are described. First, *monopolisation* illustrates the process by which scientists claim authority over scientific knowledge and practices, and deny those who are outside of what they conceive to be science. These ‘outsiders’ are considered as ‘pseudo-science’, ‘deviant’, or ‘amateur’ (Gieryn, 1983). Second, *expansion* occurs when scientists stretch out the boundaries of their activity to spaces already claimed by others. This boundary work is illustrated by the struggles between the church and science; for instance, the struggle between John Tyndall and the Clergy of Victorian England claiming the power of prayers of crises and epidemics (Gieryn, 1983, 1999). Third, *protection of autonomy* relieves scientists from being responsible for the consequences of their work.

These works showed that the boundaries between science and other activity such as politics, industry, religion, and so on are changing and are being renegotiated over time depending on the context and the actors. This entangled-domain perspective brings a richer view to study and analyse science and its interplays with politics. The next section introduces studies that go a step further by considering these boundaries permeable.

1.4.2 Blurred boundaries and involvement of multiple actors in the scientific activity

The technology and innovation management literature has largely dealt with the transformation of science that occurred since the end of World War II. Modern science is characterised by an increasing blurring of the boundary between science, the state, and industry. Governments are further involved in steering science through top-down scientific and technology policies, and oriented funding. The demarcation between science and industry has become more permeable with the creation of hybrid laboratories that host both public and private research, but also with the increase of entrepreneurial science. These transformations have been described by various concepts such as ‘Mode 1’ versus ‘Mode 2’ types of organisation of science (Gibbons et al., 1994; Nowotny et al., 2003), the Triple Helix model (Leydesdorff & Etzkowitz, 1998a; Leydesdorff & Meyer, 2007; Leydesdorff, 2000), or new forms of complementarities (Bonaccorsi, 2008).

Governments are more involved in scientific activity in order to stimulate and orient scientists towards areas that could benefit society, both economically and socially. This research prioritisation occurred at both the national and supra-national levels. These programmes aim at bringing more coherence between, but also additional, resources. A good illustration of these initiatives is the *European Framework Programmes* (abbreviated FP as in FP1 to FP8, also named *Horizon 2020*). They started in 1984 and had a span time of four years until FP6. They have been expended to six years since FP7. At the national level, changes occurred as governments tend to fund specific programmes that cross the usual ones of the ministries of health, agriculture, industry, and so on (Nowotny et al., 2003). The next changes that these different concepts describe are the rise of entrepreneurial science (Etzkowitz, 1998; Louis, Blumenthal, Gluck, & Stoto, 1989) and the commercialisation of research along with the exploitation of intellectual property (Nowotny et al., 2003). This can be observed with the development of the patenting and licensing activity within universities (Thursby, Fuller, & Thursby, 2009; Thursby & Thursby, 2011a) and with the increase of firms spun off by universities (Murray, 2004).

Bonaccorsi (2008) adds that these new forms of science are formed around ‘objects’ (p.290) that are more complex than the traditional problems tackled by traditional disciplines. Moreover, these new sciences grow faster than traditional disciplines and, even when reaching maturity, tend to produce more sub-disciplines. Then, based on a study of keywords, Bonaccorsi (2008) shows that these new forms of science are more diverse (more new keywords are constantly emerging compared to established disciplines) and can host competing theories, whereas competition between concepts in traditional sciences would lead to doubts being cast on the established paradigm (Kuhn, 1970).

Politics of budget reduction that happened in most of the OECD countries since the late 1970s (Braun, 2003) triggered these changes and, with the shift from recurrent to project-based funding (Whitley, 2007), scientists have become more and more dependent on external financial resources (Laudel, 2006a). This system aims at encouraging the best scientists by providing them with funding for their projects (Laudel, 2006b). By doing so, policy makers become able to steer, to a certain extent, the various disciplines towards areas that are of greater social, economic or social interest (Braun, 2003). The reduction of public funding has led to two main consequences. On the one hand, scientists who want to do research tend to move to more profitable areas and on the other hand, scientists who are more successful in gaining grant money tend to become leaders. This tends to challenge the established scientific hierarchy. Scientific value is therefore more difficult to gain, as not only do publications build reputations, so too does the ability to obtain external funding (Braun, 2003). The competitive system enables policy makers to better steer science and to increase the distribution of funding, in addition to motivating scientists and fostering the emergence of new research ideas (Liefner, 2003).

Related to the rise of entrepreneurial science, both the role of scientists (Jain, George, & Maltarich, 2009) and the tasks assigned them (Casati & Genet, 2012) have been modified. Scientific entrepreneurs, or principal investigators, play a role in the blurring of boundaries between science and other activities. Indeed, even though the continuum of scientific research goes from basic to applied science, scientists are more and more asked in their applications for funding to consider the potential economic or societal benefits of their research. This is even more accentuated when an industrial partner is involved. Principal investigators, through the management of projects, have to link their research with the requirements of policy makers; in other words, the activity with the institutional context (Dille & Soderlund, 2011; Engwall, 2003). Principal investigators, therefore, increase the blurring of boundaries by gathering partners from different disciplines and organisations to meet the requirements of policy makers and the research avenues that they foster.

This introductory section on the characterisation of scientific activity showed that scientific activity is not independent from non-scientific actors and that its boundaries are shaped according to these various actors. Even though the essentialist perspective defends an ‘idealistic’ view of science, which would be independent of these interrelationships, other studies have shown that science has to adapt to its environment because of its dependency on financial resources. The difficulty, to grasp the interplays between the different actors, is to include in the same framework both the micro and macro levels of analysis and to take a longitudinal perspective in order to be able to describe how the boundaries are reshaped, diffused, and institutionalised. The institutional logics perspective (Thornton et al., 2012; Thornton & Ocasio, 2008) embeds these different dimensions and provides a suitable frame to the interactions between the scientific and political spheres (Swan, Bresnen, Robertson, Newell, & Dopson, 2010).

1.5 INSTITUTIONALISATION PROCESS AND COMPOSITE BOUNDARIES

1.5.1 An institutional logics perspective

Thornton and Ocasio (1999) define institutional logics as ‘the socially constructed, historical patterns of material practices, assumptions, values, beliefs, and rules by which individuals produce and reproduce their material subsistence, organize time and space, and provide meaning to their social reality’ (p.804). The institutional logics perspective is a meta-theory (Thornton et al., 2012) that is based on four main theoretical principles. The first core assumption, which deals with the duality between agency and structure, states that ‘the interests, identities, values, and assumptions of individuals and organizations are embedded within prevailing institutional logics’ (Thornton & Ocasio, 2008: 103). Actions, in that sense, are the results of the interaction between agency and institutional structures (Friedland & Alford, 1991; Thornton & Ocasio, 1999). This first principle reflects a drastic break between institutional logics and new institutionalism. Indeed, foundational works of new institutionalism, dealing at a macro level of analysis, focused on the constraining nature of institutions (see DiMaggio & Powell, 1983; Meyer & Rowan, 1977). Although these inspiring works explain how culture and cognition shape organisations, they reach their limit when trying to describe agency;

that is, how actors at the micro level can affect and transform institutions. Institutional entrepreneurship tried to go beyond this issue by showing that individuals can transform institutions and make new ones emerge when they see new possibilities in them and are able to gather resources (DiMaggio, 1988). This view has been criticised for describing a small set of actors as heroes (for instance, Maguire, Hardy, & Lawrence, 2004) who is not constrained by extant institutions. More research on institutional entrepreneurship (Battilana, Leca, & Boxenbaum, 2009; Leca & Boxenbaum, 2008) furthers the concept to include the constraining nature of institutions and to characterise agency as ‘embedded agency’ (Battilana & D’Aunno, 2009). However, even though this keeps on interesting organisational scholars (Battilana, 2006; Emirbayer & Mische, 1998; Seo & Creed, 2002), the two levels are kept as dual. In order to overcome this issue, institutional logics differs from new institutionalism by including both the macro (DiMaggio & Powell, 1983; Meyer & Rowan, 1977) and the micro (Zucker, 1977, 1991) levels of analysis within the same theoretical frame; that is, both the action and the structure (Thornton et al., 2012). This is of critical importance as it implies that institutional logics are constituted by both enabling and constraining characteristics and, therefore, individuals both produce and reproduce institutions.

The second principle is based on the argument that ‘each of the institutional orders in society has both material and symbolic elements’ (Thornton et al., 2012: 10). Material refers to structures and practices, and symbolic to meaning and its conception. This is another dimension on which institutional logics and new institutionalism differ. Indeed, the latter tends to emphasise either one or the other. Scott (2003, 2008) describes the three pillars that support institutions. The regulative (or legal) pillar involves the activities of rule-setting, monitoring and sanctioning, and has mostly been tackled by institutional economists and economic sociologists (Scott, 2003). Organisations have to comply with these rules if they do not want to suffer from penalties. This is what makes organisations structurally look like one another (DiMaggio & Powell, 1983). The normative (or social) pillar focuses on how behaviours are socially constrained and has been studied by sociologists and social psychologists (Scott, 2003). This pillar is based on what it is expected of an individual, in a particular role, in a given situation. More recently, organisational sociologists and cognitive psychologists have paid attention to the cultural and cognitive aspects of institutions (Scott, 2003). The cultural-cognitive pillar involves symbols such as words, signs, and so on, but also the cultural frame within which each individual is embedded and which guides the construction of meaning of how it is shared. Individuals and organisations can accept and reproduce these aspects without being necessarily conscious of their existence (Zucker, 1977). Even though some studies show that institutions are constituted by all three pillars (e.g., (Hoffman & Ventresca, 1999; Hoffman, 1999) and that they are interrelated (Hirsch, 1997), institutional logics consider central these three elements and their interconnections within each institutional order (Thornton et al., 2012).

The third principle implies the *historical contingency of institutions*. This means that the regulative, social and cognitive aspects of institutions can be valid in one period of time and not in another (Friedland & Alford, 1991). As described by Thornton et al. (2012: 12), modern societies are influenced by different institutional orders, which are the state, the profession, the corporation, and the market. The market logic has been more and more prevalent over the past thirty years and has transformed a number of industries. In the higher education publishing industry, for example, Thornton and Ocasio (1999) show that the relationships between an author and the editor, as well as the publishing houses' internal growth, is different under an editorial or a market logic. Thornton and Jones (2005) extend this work in an analysis of the accounting, architecture and publishing industries by describing how governance is influenced by the aforementioned institutional orders. Interestingly, Marquis and Lounsbury (2007) show that competing logics can be a source of resistance to institutional change by describing how the rise of a large market-based banking logic was slowed down by the entrepreneurial community-based logics.

Institutions as multiple levels of analysis is the fourth foundational principle of institutional logics. Individuals, organisations, fields, and society are the different levels that constitute institutions (Thornton et al., 2012). Moreover, Friedland and Alford (1991) bring the fundamental assumption that institutions contain both constraints and opportunities for change. By operating at multiple levels of analysis, it is, therefore, essential to understand from which level opportunities and constraints come and what are the consequences on the other levels.

This section locates the institutional logics in comparison to the dominant theory of new institutionalism. Although the institutional logics perspective takes its roots in new institutionalism, it differs from it in multiple ways. It reintegrates both the constraining aspects of institutions and their microfoundations. In this way, the duality between these two levels disappears to favour the interlevel influences and to allow for a finer-grained analysis of the roots of an institutional change. I will now focus on how institutional logics are defined in the literature and how the different works can help to frame the present study.

1.5.2 A composite boundary framework to the institutionalisation process

Whether it be a sociological, economic or science and public policy perspective, boundaries are central and they also are of tremendous importance in organisation studies. Delineating boundaries is essential at various levels. At the industry level, interactions between members over time shape the cognitive frames that tie the industry together (Porac, Thomas, & Baden-Fuller, 2011; Porac, Thomas, Wilson, Paton, & Kanfer, 1995). These cognitive frames are at the basis of the formation of collective identities (Wry, Lounsbury, & Glynn, 2011). At the organisational level, boundaries are a prerequisite for an organisation to exist. Santos and Eisenhardt (2005) define organisational boundaries as a 'demarcation between the organization and its environment' (p.491) and identify four types of organisational boundaries: power, competence, identity, and efficiency. Although attention has been paid to the formation of new organisational fields, mostly from an institutional theory perspective (Lawrence, Hardy, & Phillips, 2002; Maguire et al., 2004), the study of the boundaries themselves has been overlooked (Paulsen & Hernes, 2003).

A second stream of research (see Heracleous, 2004; Hernes & Paulsen, 2003; Hernes, 2004a, 2004b) describes boundaries as a relational process that is essential for the constitution of any group and is in constant construction and reconstruction. Moreover, instead of focusing on the delineation between the organisation and its environment along one dimension such as power, identity, competences or efficiency (Santos & Eisenhardt, 2005), this stream favours a composite analysis of boundaries, which involves three levels: physical (infrastructures and rules), social (identity) and mental (cognitive structure). These boundaries are conceptually related to Scott's (2008) institutional pillars: physical boundary for the regulative pillar, social boundary for the normative pillar, and mental boundary for the cognitive pillar. The concept of boundary is interesting as it involves both the inner and outer actors and with this second stream, several types of boundaries are studied at the same time.

The reshaping of extant boundaries and construction of new ones are a prerequisite for a field to emerge as it enables the specification of roles, behaviours and interactions between the actors involved in a field (Hinings, Greenwood, Reay, & Suddaby, 2004).

So, while the construction of boundaries remains fundamental in an emerging field, less is known about how external actors influence the construction of the boundaries of an emerging area at both the field and the organisation level; in other words, the influence of non-scientific actors on the emergence of a new scientific discipline has been neglected (Granqvist & Laurila, 2011). If the political structure of funding in science – science and technology policies and funding agencies – has been studied to understand the changes in the system, the relationships between policy and science or the role of science in the society (Martin, 2003), little is understood about how political programmes impact the conditions of emergence of a new scientific discipline. As funding is both a condition for a discipline to emerge (Frickel & Gross, 2005) and a means to control science (Braun, 1998), this context is suitable to study this process.

1.6 FRAMING THE RESEARCH QUESTION

Non-scientific actors – such as policy makers - are not outside of the sphere of science and can have an influence on it (Granqvist & Laurila, 2011). However, the extent to which they impact the scientific activity and reshape the boundaries of science has been overlooked. This study, therefore, aims to answer the following research question:

Can policy makers influence the emergence of a new scientific discipline?

Through different streams of literature, two levels of analysis and of importance have been identified. First, at the more general level, it is necessary to understand the extent to which policy makers ease the emergence of a new discipline. Through the definition of research schemes and funding of infrastructures, scholarships, networks, and so on, policy makers create new spaces that aim at facilitating scientists to move to and research these areas. Drawing boundaries is a prerequisite for a new science to exist as it is within these boundaries that scientists will be able to claim their authority (Gieryn, 1999). However the emergence of a new discipline comes from a change from within the boundaries of science. While policy makers try to steer the management of science, this questions the extent to which these new spaces facilitate and precede the emergence of a new discipline where scientists will produce, share, and cumulate knowledge (Merton, 1973) in order to build a new paradigm (Kuhn, 1970). This leads to the first sub-research question of the study:

To what extent can powerful actors, such as funding agencies, trigger institutional change by influencing the reconfiguration of the boundaries of science?

These complex intertwinements (Vermeulen et al., 2007) can be better understood through the prism of institutional logics (Thornton et al., 2012; Thornton & Ocasio, 2008). This newer perspective includes within the same frame both the deterministic view of institutions (Meyer & Rowan, 1977) and individual actions (Zucker, 1977), and provides a suitable frame to study this phenomenon (Swan et al., 2010).

Second, at the meso-micro level, these new spaces are inhabited by scientists from diverse backgrounds. This implies that they were trained in different ways of thinking, methods, protocols, and so on. Even though multidisciplinary teams tend to produce outcomes that tend to be more diverse than those produced by monodisciplinary teams (Porac, Wade, Fischer, & Brown, 2004), the extent to which they share common assumptions is not very clear. Looking at this second level analysis leads to the second sub-research question:

How do scientists involved in a scientific area crossing multiple scientific disciplines use multidisciplinary knowledge in order to create a new scientific outcome?

Reaching consensus about theoretical foundations, methods, and so on is essential for knowledge accumulation. It is also important to focus on this meso-micro level to understand what is happening within these spaces created by policy makers. Boundaries, again, provide a fruitful entry point to clarify the interactions between various scientists (Hernes, 2004b).

By answering these two sub-research questions which focus on two different levels of analysis will provide more understanding on the intertwinement between multiple institutional logics (Lounsbury, 2007; Seo & Creed, 2002; Thornton et al., 2012) as well as the impacts on practices. This will set the theoretical foundations to better understand the emergence and evolution of nanotechnology in Ireland from the late 1990s onwards.

1.7 OUTLINE OF THE STUDY

The following chapters of the study will be organised as follows. The next section, chapter 2, presents the overall methodology. A comparative case study research design has been chosen to untangle the multiple dynamics and to strengthen the theoretical understanding. A focus on qualitative data has been selected for their richness to bring light to complex events. Then, chapter 3 details the general context of scientific policies and of nanotechnology in Ireland as well as presents the six cases that have been investigated. Chapter 4 focuses on the macro level to explain the extent to which policy makers reshape the physical boundaries of the established disciplines. In chapter 5, the boundaries that scientists face at the micro level are highlighted. Chapter 6 concludes this study by providing a new angle to the emergence and evolution of nanotechnology, and will underline the future directions for research.

Chapter 2.

Ontological, epistemological and methodological approach

2.1 INTRODUCTION

Choosing the appropriate methodology is essential in a study. It is a difficult step as the results obtained through the different methods depend on the form of knowledge – epistemology – and the way in which I consider the nature of reality – ontology. It is also crucial regarding the research question as the all three are interrelated and provide a frame to interpret the results. To answer the main research question - Can policy makers influence the emergence of a new scientific discipline? – I use a composite boundary framework (Hernes, 2004a) within the frame of institutional logics (Thornton et al., 2012). This implies that I do not focus on stability in social structure but rather on emergence and evolution, which is in line with a process ontology (Langley, Smallman, Tsoukas, & van de Ven, 2013). Therefore, data collection and analysis focus on change and the extent to which boundaries are reshaped over time. I do not pretend that the knowledge built in this study is true but rather that a systematic methodology enables to describe and to objectivise a reality that can only be apprehended imperfectly (Guba & Lincoln, 2005). I use a qualitative comparative case study approach to describe both the similarities and dissimilarities between the cases. I selected six cases to have, although imperfect, a picture of the area of nanotechnology in Ireland. Dataset was analysed through a grounded theory approach in order to have the possibility to build new constructs within a general theoretical frame (Siggelkow, 2007)

2.2 PROCESS ONTOLOGY: A CONSTANT RECONFIGURATION OF BOUNDARIES

Tackling the ontological assumptions that underline a study means questioning the different nature of reality: is reality external to individuals or the ‘product of individual consciousness’ (Burrell & Morgan, 1979: 1)? Substantial questions related to this are: Is reality objective or subjective? Is it ‘out there’ or the ‘product of one’s mind’ (Burrell & Morgan, 1979: 1) or, to push it forward, the result of socio-interactions between individuals? Before positioning this study, it is important to introduce a long standing debate about incommensurability versus multi-paradigm perspectives.

A paradigm can be defined as a set of ontological (what reality is), epistemological (the type of knowledge that can be grasped from this reality), and methodological (how to obtain this knowledge) assumptions. Burrell and Morgan (1979) define four paradigms in social sciences that stand along two dimensions: objective-subjective and order-conflict. The first dimension defines whether reality is external to the individual or a social construct and the second dimension is the focus of attention, whether it is on stability and integration or on change and conflict.

Table 2.1: Four paradigms for the analysis of social theory

CONFLICT

SUBJECTIVE	‘Radical humanist’	‘Radical structuralist’	**OBJECTIVE**
	‘Interpretive’	‘functionalist’	

ORDER

(source: Burrell & Morgan, 1979: 22)

The functionalist paradigm is the dominant paradigm within which positivism and postpositivism (Guba & Lincoln, 2005) are embedded. Burrell and Morgan built this matrix to diminish the hegemony of this dominant paradigm by showing that social science is made of multiple paradigms that cannot be compared; in other words, they are incommensurable (see also Kuhn, 1970). Gioia and Pitre (1990), among others (see Kincheloe, 2001; Scherer & Steinmann, 1999; Schultz & Hatch, 1996; Weaver & Gioia, 1994), argue that, even though valuable, building theories within the doctrine of only one single paradigm would provide a limited view of organisational knowledge and the problem of incommensurability must be overcome. To overcome this issue, they propose four transition zones, which are based on the similarities of the two paradigms they bridge in order to benefit from the strengths of both. The exchange between Jackson and Carter, and Willmott is very illustrative of the vivid dialogue between the two camps (see Jackson & Carter, 1991, 1993; Willmott, 1993a, 1993b). This introduction gives a frame of the ontological issues that stand behind a process approach and the extent to which it differs from more established ontologies.

A process perspective focuses on how phenomena emerge, change, and end over time (Langley et al., 2013) and takes the view that individuals, organisations, and their environments are in constant, interacting flux (MacKay & Chia, 2013). The environment is not something constant and outside of changing organisations, but is continually reconstituted by the interactions with the organisations and individuals (Meyer, Gaba, & Colwell, 2005). First, the process perspective bridges the order-conflict dimension by discussing the degree of change (Gioia & Pitre, 1990) through acknowledging that structure exists and constrains individuals. Second, the process perspective questions the subjective-objective nature of reality. This view finds some similarities with structurationist theorists, such as Giddens, to consider structures as both ‘a flow of ongoing actions and as a set of institutionalized traditions or forms that reflect and constrain’ actions (Barley, 1986: 80).

Process ontology has some similarities and dissimilarities with the paradigms located along the two dimensions described above and, therefore, cannot be embedded within only one of them. It finds similarities when including the degree of change and both the constraining and ongoing nature of structure, but differs from all of them in one major point. Indeed, by placing process at the centre of study, change is no longer considered exceptional (Tsoukas & Chia, 2002) and organisations are no longer stable entities but are seen as a bundle of qualities of which some are more persistent than others (Langley et al., 2013).

Process ontology can be divided into two branches. First, the ‘weak’ process approach is grounded in substantive metaphysics, where processes represent change in things (Langley et al., 2013). Nature is made up of stable substances that change only when they move in space and time. Organisations do not change, even if their qualities are changing. Second, the ‘strong’ process approach sees the reifications of processes over substances. ‘Things’ in Nature are in constant fluctuation. The usual example for the strong process approach would be a river, which is not a thing, but a constant, moving flow (Resher, 1996, cited by Van de Ven & Poole, 2005). This approach focuses on verbs, such as sense making or organising, rather than on nouns.

2.3 EPISTEMOLOGY: REALITY AS A CONCRETE PROCESS

Epistemology deals with the form of knowledge that can be obtained and whether it can be characterised as true or false (Burrell & Morgan, 1979). It questions the nature of knowledge itself and whether it is real and can be transmitted, or it is softer and more subjective. Guba and Lincoln (2005) identify five main paradigms: positivism, postpositivism, critical theory, constructivism, and participatory. Each of them implies a different nature of knowledge that ranges from verified hypotheses to living knowledge and, therefore, different views of knowledge accumulation (see Table 2.2).

Table 2.2: Paradigm positions on selected issues

Issue	Positivism	Postpositivism	Critical theory	Constructivism	Participatory
Nature of Knowledge	Verified hypotheses established	Nonfalsified hypotheses that are probable facts or laws	Structural/historical insights	Individual and collective reconstruction sometimes coalescing around consensus	Extended epistemology: primacy of practical knowing; living knowledge
Knowledge accumulation	Accreditation – ‘building blocks’ adding to ‘edifice of knowledge’: generalisations and cause-effect linkages		Historical revisionism; generalisation by similarity	More informed and sophisticated reconstruction; vicarious experience	In communities of inquiry embedded in communities of practice

Source: Extract from Guba & Lincoln (2005: 196)

This study is embedded in the frame of critical realism and a postpositivist perspective. Reality is considered as a ‘concrete process’ (Morgan & Smircich, 1980: 492). It implies that individuals are influenced by but also can alter their environment. The epistemological stance particularly focuses on understanding systems, processes, and changes. So, structures are independent ‘of our knowledge of them’ (Tsoukas, 1989: 552) and, therefore, reality exists, but, considering its complexity, can only be apprehended imperfectly (Guba & Lincoln, 2005).

Critical realism is embedded in the postpositivist paradigm and three points are to be discussed in order to balance some basic assumptions related to this paradigm. First, in a process view, structures shape individuals’ interactions and are reproduced in interactions. Within this structuration process, change can occur as individuals are not totally constrained by those structures, but have some degree of liberty, defined as agency in new institutionalist (Battilana & D’Aunno, 2009) or praxis in dialectical (Seo & Creed, 2002) approaches. To borrow Barley's (1990: 244) words describing his research field, this study is ‘structuralist in orientation and realist in tone’.

Second, generalisation is essential for knowledge accumulation (Guba & Lincoln, 2005). Events take place in open systems and are subject to multiple variations (Stablein, 2006; Tsoukas, 1989). It is by identifying these variations and their causality that social sciences are made possible. However, regarding a process perspective, these causal variations are also embedded in a constant flow, which makes generalisation very difficult. Even though replication has been encouraged (Tsang & Kwan, 1999) by using the same dataset or population, or with a different population, pure replication seems not to be possible. Generalisation by similarities, and dissimilarities, is more appropriate to take into account the variances that are common between two studies, but also to identify those that have changed, or that have been less enduring, in the constant flow of change.

The third point is the place of the researcher and his/her influence on a study. A researcher who is going to conduct interviews brings his/her background, values, and mood (for an extreme example see Goode, 2002). This is especially important during the exploratory stages of fieldwork, when interviews are less formalised and take the form more of a discussion than of a structured interview. Methodological provisions are taken to make the data more objective such as the details of the data collection and the use of memos, and data analysis. However, the influence of the researcher cannot be denied in the process.

Balancing some points related to the postpositivist paradigm does not mean the rejection of this epistemological approach. Indeed, critical realism differs from positivism where reality can be reached (Guba & Lincoln, 2005) and from constructivism where reality is merely socially constructed (Ackroyd & Fleetwood, 2000). By bringing new insights, critical realism has been more and more discussed in organisational studies (Al-Amoudi & Reed, 2011; Rafols & Zwanenberg, 2010; Reed, 1997; Tsang & Kwan, 1999; van de Ven & Poole, 2005).

2.4 METHODOLOGY

2.4.1 Research design: A comparative case study

A research design is the ‘logical plan’ that will draw the different steps to go from the research question – or at least the first questioning with which a researcher goes to the field – and the conclusions of the research (Yin, 2009). Establishing these guidelines is, therefore, an essential step in order to produce rigorous research (Vermeulen, 2005). The critical points of a research design deal with linking the questioning and the fieldwork, defining the data that will be relevant for the study, collecting those data, and analysing them. Among the different types that a research design can take, I here focus on case study and its two variants: single-case and comparative-case study. Comparing different cases was central to this study. Indeed, multiple actors were involved during the phase of emergence of N&N which led to specific dynamics. By comparing both the similarities and dissimilarities of the cases allows the picture of the dynamics across various actors to be richer and to understand how they react under the same institutional pressures. In this study, the aim is to describe the extent to which new spaces – funding schemes, infrastructures, and so on – trigger the drawing of new boundaries. Previous studies suggested that during the phase of emergence not all actors move to the new area even though they have the capability to do so (Granqvist, Grodal, & Woolley, 2012). It is, therefore, interesting to deepen the dimensions along which actors commit to the emerging area. The comparison of different cases is a suitable research design, as N&N involved diverse actors from the scientific and policy spheres, but also from multiple scientific disciplines.

Case study is a research strategy that allows a researcher to investigate contemporary phenomena such as individual and organisational life cycles, organisational and managerial processes, changes, and so on in their real-time context, and when boundaries are difficult to establish (Yin, 2009). It can be used for different purposes such as exploring and explaining new, complex organisational situations, describing an event and its context, fostering new ideas, illustrating a conceptual statement, and so on (Siggelkow, 2007; Yin, 2009). Moreover, it is particularly suited to answer ‘why’ and ‘how’ types of questions.

A case study research design was chosen as it allows to study the processes and the dynamics within defined boundaries (Eisenhardt, 1989). This research design was, therefore, suited for this research for two reasons. First, this study involved multiple levels of interactions (Hitt et al., 2007). Indeed, focusing on the influence of policy makers on the emergence of a new discipline involved the taking into account of the political environment, scientific activity within the area of N&N, and organisations – laboratories – that are embedded in this complex environment. Moreover, case studies are suited when the phenomena studied can hardly be distinguished from their contexts (Yin, 2009) and when having a deep understanding of the context is of critical importance (Dyer & Wilkins, 1991).

Second, case studies are a suitable design to generate novel hypotheses (Leonard-Barton, 1990) and theories (Eisenhardt & Graebner, 2007; Eisenhardt, 1989). Even though the interplays between science and policy has been tackled by different disciplines, such as sociology of science or research policy, the institutionalisation process and the extent to which policy makers can steer the scientific are still lacking of understanding. Indeed, sociology of science tends to have an inner perspective of this activity (see Frickel & Gross, 2005) and research on scientific public policies tends to draw a view at the field level, which stamps out the interlevel interactions and what happens within scientific organisations (see Bonaccorsi, 2008; Leydesdorff & Etzkowitz, 1996).

Even though a well-selected single case study can provide readers with new insights (Dyer & Wilkins, 1991; Siggelkow, 2007), including multiple cases is a way to build stronger theory (Bono & McNamara, 2011; Eisenhardt, 1991; Tsang & Kwan, 1999). Comparing over several cases allows the common patterns between cases to be more relevant and the constructs to be more accurate and richer (Eisenhardt, 1989, 1991; Yin, 2009). Comparative case study research design allows the researcher to include both the similarities and dissimilarities that can emerge between the cases.

2.4.2 Selecting the cases

Cases must be chosen because they present characteristics that suit the study (Pettigrew, 1990; Siggelkow, 2007). Cases were chosen to understand the various dynamics that can occur during the phase of emergence. Therefore, they were not selected because they offer similar characteristics that would lead to look for literal replication (Yin, 2009). Indeed, this would restrain the richness of the dynamics and leave the literature that emphasises this diversity. Moreover, cases were not selected to test and to reinforce an extant theory through theoretical replication by trying to find contradictory results. Indeed, the aim of the study is to build theory in order to make sense of this event. Selection of cases was meant to represent the variety of N&N in terms of disciplines involved and the different structures.

First, cases were selected within the area of N&N. This is a topical area (Bozeman, Laredo, & Mangematin, 2007; Mangematin & Walsh, 2012) that is studied within different disciplines of social sciences and, therefore, along different dimensions and levels. Choosing an area that has already been investigated enables to have a backdrop for the research and insights for the interpretation of the results (Barley, 1990). As this area lacks definitions and, therefore, it is not possible to define precisely which organisations are in the area and which ones are out, an approach through publications was used in order to have a first general picture of what N&N in Ireland is. Mogoutov and Kahane (2007) developed a methodology based on keywords to track N&N academic articles to go beyond journal categorisations. Using an extract of a worldwide database – at least one of the authors' institutions is located in Ireland – enabled to identify the main organisations, laboratories, and authors that are involved in this area. N&N is a worldwide phenomenon, and the trends observed in Ireland were in line with those in other OECD countries (Palmberg, Dernis, & Miguet, 2009).

Second, the choice of the first case is critical, as it has to be selected not only because of its intrinsic characteristics (Siggelkow, 2007), but also to verify the literature against the fieldwork and to generate new ideas (Eisenhardt, 1989; Yin, 2009). As N&N is said to bring various disciplines together (Heinze & Bauer, 2007; Schummer, 2004a), multidisciplinary laboratories were the first choice to go into the field. These cases present more the extreme characteristics (Pettigrew, 1990) of N&N than monodisciplinary laboratories; that is, the three main disciplines (physics, chemistry, and biology) were represented in the laboratory.

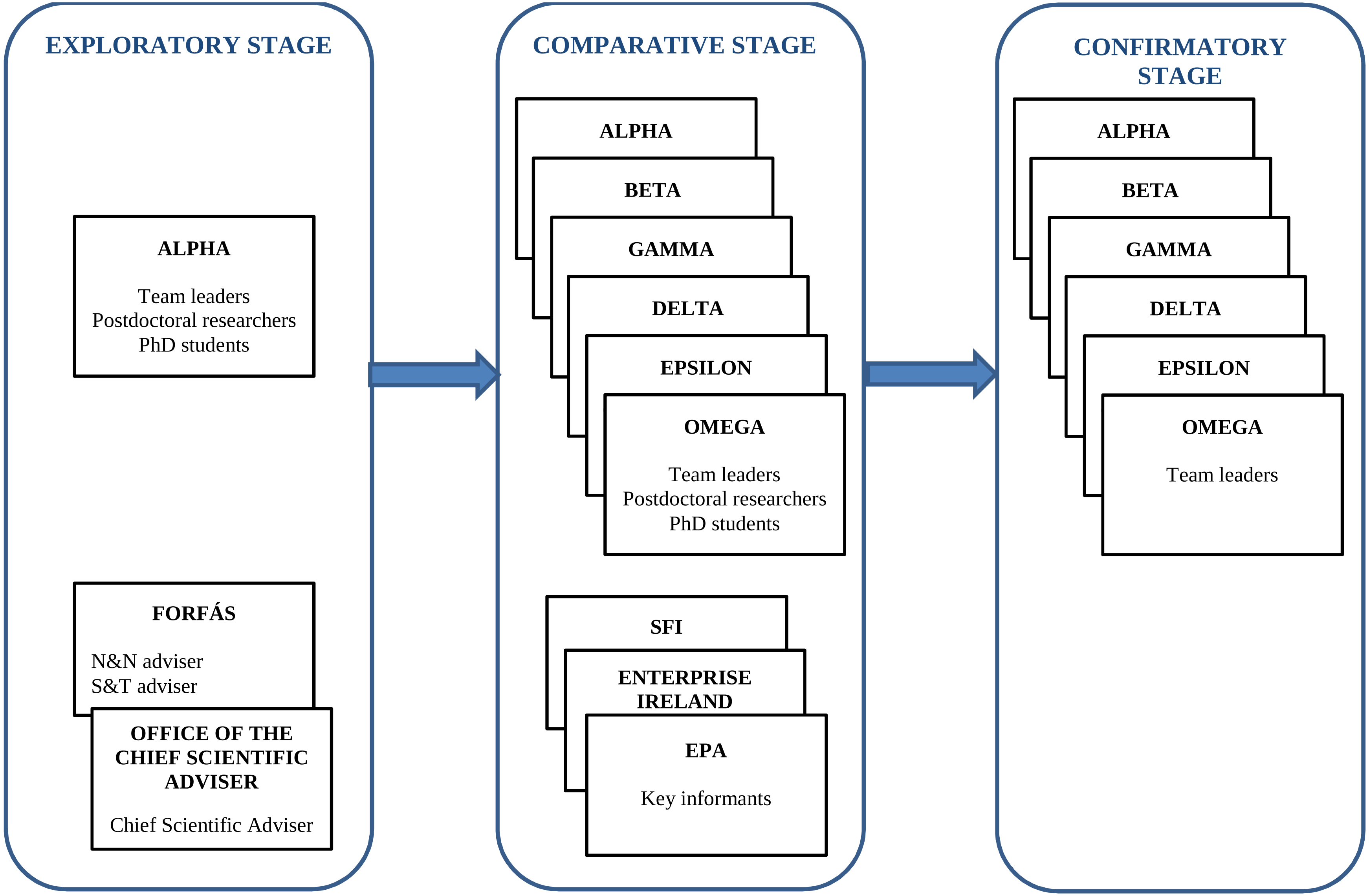
Then, the selection of the first case was influenced by non-scientometric criteria. First, as I do not have any background in physics, chemistry, or biology, or any laboratory experience, I needed a case that would allow me frequent access (Barley, 1990). Thus, geographically close cases were favoured. Then, as I would need to go regularly to the laboratory to have informal talks and observations in order to become more familiar with a research laboratory, availability of the members was also taken into account (Leonard-Barton, 1990). Spending time in the laboratory allows trust to be built with the members which is an essential aspect to have access to information (Dutton & Dukerich, 2006).

Other cases were also chosen because of their presence in the database. However, not only extreme cases were selected. Indeed, picking up only multidisciplinary laboratories would not provide a fair picture of N&N. Indeed, although N&N crosses multiple disciplines, physics and chemistry are the central disciplines (Bassecoulard, Lelu, & Zitt, 2007). In this way, laboratories conducting research within these disciplines were also selected. Advertising N&N was not a criterion to choose cases, as, even though some had the capabilities, not everyone was committed to this area (Granqvist et al., 2012). The same non-scientometric criteria were used to sample the case. Then, to increase the trustworthiness with the members of the different cases, a summary of the project was sent prior to any interview (see Appendix B p.206 for details). In the same way, to contact the next selected case, I asked whether I could use the name of the team leader I already interviewed in order to increase peer approbation and to ease the contact. Case studies were conducted until theoretical saturation (Glaser & Strauss, 1967). At the end, six case studies were conducted: Alpha, Beta, Gamma, Delta, Epsilon, and Omega. These are pseudonyms, as anonymity was a prior requirement to any case study. Cases are further detailed in Chapter 2.

2.4.3 Data collection: A qualitative approach

A grounded theory approach (Glaser & Strauss, 1967; Strauss & Corbin, 2007) was used in this study. In that sense, data collection and analysis are largely intertwined, but, on a point of clarification, the two will be distinguished from one another. Even though quantitative data were collected to map out and to give a broad picture of the area of N&N in Ireland, the data that were used to answer the research questions are qualitative. Qualitative data provide very rich materials (Miles & Huberman, 1994) and enable to describe processes, as well as who says what and the rationales behind the statements (Gephart, 2004). Moreover, this particular type of data allows the researcher to study a phenomenon within its environment (Denzin & Lincoln, 1994), which is in line with the research questions. By emphasising the processes and meaning of the entities that are studied, qualitative data, and their analysis, enable to make visible a certain representation of the word (Denzin & Lincoln, 1994). Understanding the events over a long period of time was crucial to describe the changes that occurred in the dynamics (van de Ven & Huber, 1990). The data collection was organised in three main stages and lasted from May 2009 to December 2011. The first was exploration and, after having narrowed down the research question, the second stage involved collecting more precise information. The third and last stage was realised to verify the data collected during the second stage with the key informants of each case, and to ask follow-up questions (see Figure 2.1).

Figure 2.1: Data collection process



The first stage was a phase of exploration during which the research question was not yet fully narrowed down. So, the first data were important to grasp potential new directions (Eisenhardt, 1989; Yin, 2009). First, interviews were conducted with scientists that held key positions (Pettigrew, 1990) in a laboratory, which was chosen for its peculiar characteristics (Siggelkow, 2007). These were open interviews and themes about N&N and the science and technology policy system were tackled. The same themes were tackled with the postdoctoral researchers and PhD students of the group in order to avoid elite bias (Miles & Huberman, 1994) and to have a richer dataset (Eisenhardt & Graebner, 2007). After each interview, and throughout the different phases of the research process, a memo was written to keep track of the context within which the interview was conducted, such as place and time pressure, but also informal information about the interview in itself, such as the ‘mood’ of both the interviewee and interviewer, whether the interviewee answered and understood the questions, as well as the overall feeling of the interviews. This was very helpful after having conducted several interviews to get the context back in mind and to reinterpret the tone of the data. During this phase of exploration, open interviews were also conducted with the members of the science and technology policy (STP) community to have an understanding both of the funding system at large and of N&N.

In the second stage of data collection, information was gathered in order to answer a more narrowed research question. This round of data collection started with an interview of the team leader to gather information about the research activity and its purpose, the discipline and how it is funded, and the members of the team and how it is organised. Then, information was gathered according to an interview guide (see Appendix C p.210), where the themes and questions were built according to the information collected during the first stage. In order to identify the disciplinary boundaries, the first theme tackled the trajectory that the scientists pursue to come to N&N. Combining longitudinal with retrospective data can bring complementarities and synergies to the analysis (Leonard-Barton, 1990). To limit the *a posteriori* reconstruction (Weick, 1995a) of the scientist's path, the CV was used to identify each crucial step from graduate study to the current position. Motivations were deepened through the discussion of what made the scientist come to this area of science, whether it be a person, an organisation, or something else. The second theme focused on the organisation and the different strands of research conducted. This is practice-oriented and aims at clarifying the ways in which scientists practice research; in other words, the scientists they collaborate with for both experiments and articles, and the conferences and journals that are targeted. These questions highlighted both the disciplinary and organisational boundaries. The last theme aimed at deepening N&N by locating the research and the laboratory among the competitors, and the sense that the scientist has of N&N. This interview guide was also applied to postdoctoral researchers, if any, and to PhD students across all six cases. All interviews were conducted in the workplace of the interviewees to favour and take into account the context with the focus of the interview (Weick, 1995a). Given the interviewees' schedules, most of the interviews were conducted under time constraints. This limitation was offset by the selection of geographically close cases that granted easier and more frequent access (Barley, 1990).

During this second stage of data collection internal documents were also collected that helped explain the evolution of the laboratory, such as the applications for funding, as well as the projects that were currently conducted within the organisation (see Table 2.3). Each interview was recorded and taped. Then, they were sent to the interviewee for validation (Pettigrew, 1990).

Table 2.3: Details of data collected about the scientific community

	Alpha	**Beta**	**Gamma**	**Delta**	**Epsilon**	**Omega**
Team leaders	150 (2)*	25 (1)	30 (1)	30 (1)	35 (1)	30 (1)
Postdoctoral researchers	45 (2)	90 (5)	130 (6)	none	10 (1)	15 (1)
PhD students	95 (5)	20 (1)	35 (3)	60 (4)	35 (2)	40 (3)
Documents	280	150	100	20	25	20
Book	1	none	none	none	none	none
Total**	**575**	**285**	**250**	**110**	**105**	**105**

*Single-spaced pages (number of scientists interviewed)

**Approximate number of pages

The second part of the data collection during this stage was the gathering of information about the funding system, and its evolution, of N&N. The main materials for the STP community are the documents that are produced by the different agencies. The annual reports from 1999 to 2010 for the Forfás agency were gathered in order to define the evolution of N&N from the side of policy makers. This was complemented by documents from Science Foundation Ireland, Enterprise Ireland, the European Union, and the Irish Environmental Protection Agency. Once a chronology of the evolution of N&N was established, dates and events were checked with the key informants from the main agencies (see Table 2.4). As for interviews conducted with scientists, they were recorded, taped, and sent to the interviewees for validation.

Table 2.4: Details of data collected about the STP community

	Government	**Forfás**	**SFI**	**EI**	**EU**	**EPA**
Interview	15 (1)*	65 (2)	15 (1)	30 (2)**		5 (1)
Documents	250	1700	240	100	210	150
Total***	**265**	**1765**	**255**	**130**	**210**	**155**

*Single-spaced pages (number of individuals)

**These delegates to N&N are also the contact point the Seventh European Framework Programme and therefore they have been interviewed in quality of both roles

*** Approximate number of pages

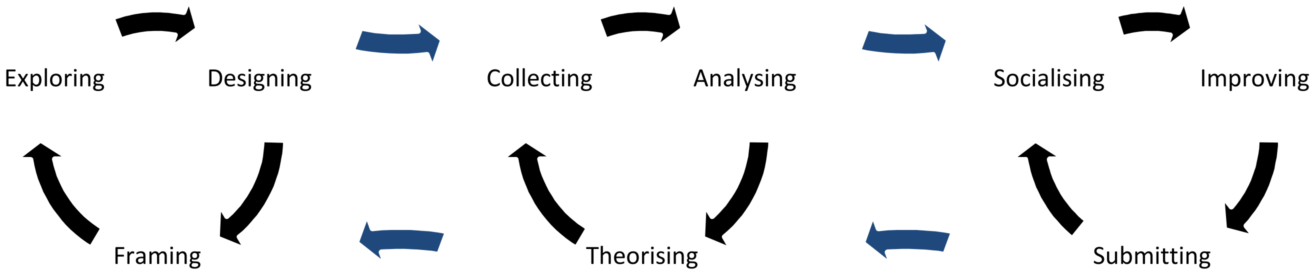
After having analysed the data collected during the second round, the third and last round of data collection consisted of confirming the emerging results and adding the missing pieces of information. First, the descriptions that were used in order to describe the evolution of each team and its physical, social, and mental boundaries were confirmed (Hernes, 2004a, 2004b). This was then triangulated with information about the different projects, and the diffusion of the results in both conferences and journals. Then, the vision of the evolution of their respective discipline was discussed with each key informant of the scientific community. Future claims are important elements to understand the construction of identity at both the individual and organisational levels (Schultz & Hernes, 2012). Information was deepened until reaching the point of saturation (Strauss & Corbin, 2007; Suddaby, 2006), where new information confirmed previous data and did not bring any new insights.

2.4.4 Data analysis: A grounded theory approach

‘*How can I know what I think until I see what I say*’ (Weick, 1995: 18).

Weick’s citation is a good illustration of the grounded theory approach. Sense emerges along with the data collection process and its intertwinement with data analysis and theory building. A grounded theory approach (Strauss & Corbin, 2007) was used to analyse the data. Grounded theory is suited for this study as the main goal is not to test or improve an extant theory against a new fieldwork, but to provide new theoretical insights to an overlooked phenomenon. Using this approach allows new themes and theoretical constructs to emerge. Grounded theory is not a random process, as it follows a methodology (Suddaby, 2006) in order to enhance the rigour of the theory construction (Barley, 2006). Data collection and analysis were largely intertwined and were organised to reach a certain degree of abstraction through the process of theorising (Weick, 1995b). In order to enhance the relevance of the study, the first results have been presented to a conference dedicated to N&N in front of physics, chemists and biologists (see Appendix D p.212 for more details). Figure 2.2 illustrates the grounded theory approach and the back-and-forth between the data and the theory. It includes three main stages even though all the steps are very intertwined with each other. The beginning of the process includes the phases of exploration, design and frame. It mainly deals with the reasons why a study is undertaken and how it has to be done. Even though in Figure 2.2 it precedes data the stage of data collection, analysis and theorisation, these two stages are largely intertwined (Miles & Huberman, 1994). The last stage includes socialisation, improvement and submission. Although these steps are not explicitly describe in methodology handbooks or articles, they are part of the research process as they enable to have feedback from the community and, therefore, to adjust the study in order to build stronger arguments.

Figure 2.2: Qualitative and abductive process



The data analysis was organised in two stages in order to answer the following research question: Can policy makers influence the emergence of a new scientific discipline? The two stages were a single-case study and the second, a comparative-case study.

The first case serves as an early step of analysis in order to allow both the collection of new and better data to fill the gaps as well as the emergence of new themes (Miles & Huberman, 1994: 50). It aimed at answering the following sub-research question: How do scientists involved in a scientific area crossing multiple scientific disciplines use multidisciplinary knowledge in order to create a new scientific outcome? Miles and Huberman advise that data collection and analysis be interwoven from the start. This strategy has enabled the emergence of the general theme of boundary construction and of sub-themes such as the centrality of equipment in nanotechnology and the issue of professional identity construction. Following this strategy, data collection and analysis will be focused on the themes that emerged during the early step of analysis, but still interwoven in order to improve the robustness of the results. Indeed, Siggelkow (2007: 21) points out the importance of theoretical guidance, while ‘an open mind is good’ to allow new themes to emerge. This first case has enabled to build a primary understanding of the interactions that are occurring within a nano-dedicated laboratory. Then, in order to construct a better comprehension of the extent to which policy makers influence the emergence of a new scientific discipline, I undertook a comparative-case analysis.

Multiple cases are very helpful to generate explanations and to advance theories (Miles & Huberman, 1994). This analysis aimed at answering the following sub-research question: To what extent can powerful actors, such as funding agencies, trigger institutional change by influencing the reconfiguration of the boundaries of science? Although crossing cases allows the researcher to avoid characteristics that are unique to each case (Eisenhardt & Graebner, 2007), both the similarities and dissimilarities between cases were taken into account. Indeed, leaving out idiosyncratic characteristics would have led to impoverishing the theoretical understanding of the phenomenon of emergence. The same methodology was replicated from one case to another (Yin, 2009), with both commonalities and differences included in the analysis. Including both aspects was important, as deepening social dynamics is not easy given they are always embedded within an environment that impacts, and is impacted by, them. As research at the micro level tends to overlook the environment (Hitt et al., 2007), the context was central to bring more understanding of the phenomenon. In order to make sense of this rich dataset, activities such as 'generalising, relating, selecting, explaining, synthesising, and idealising' (Weick, 1995a: 389) were mobilised to build the process of theorisation. This is a complex process, as the theory is constructed during the data collection and analysis and emerges through the iterative process between the data and the theory.

To make sense of data, NVivo 8 software was used. It helped to categorise the large amount of qualitative data and to improve coding skills (Yin, 2009: 128). NVivo 8 was useful for three main reasons. First, it helped to classify the data and to link attributes with each informant. Second, manual coding would not have been possible with the large amount of data collected for this study. By being able to easily handle the data, codes (or nodes) allowed the theory to emerge along the different steps of the analysis. Third, with the memos, tracking the theorisation process is possible. This is useful when the construction of themes and aggregates becomes complex and when taking a step back is required to clarify the theory construction. To trace the citations throughout the study I used the name of the lab – Alpha, Beta, Gamma, etc. – and a digit that relates to the function in the team: 1 refers to team leader, 2 to postdoctoral researcher and 3 to PhD student. Then, the last number refers the number of this function interviewed. For instance, ‘Alpha 3.2’ refers to the second PhD student interviewed belonging to Alpha. More details of each analysis are given in Chapter 4 (Section 4.3.5, p.99) and in Chapter 5 (Section 5.3.3, p.138).

2.5 CONCLUSION

This chapter describes the ontological and epistemological approaches of the study as well as the general methodology. Choosing a process stance for this study implies to look at the evolution of boundaries of the scientific disciplines and the extent to which actors have reshaped them. This methodology allows to tackle the two levels of analysis – macro-meso and meso-micro – and to provide elements to answer the two sub-research questions.

Chapter 3.

Presentation of the general context and of the cases

3.1 INTRODUCTION

Since the 1970s, Ireland has been investing in science and has started by building its first biotechnology programme. Investments have continued to increase and research facilities and education programmes have been developed to build and develop a knowledge-based economy. Ireland was a latecomer to nanotechnology as it started to fund nanotechnology in 2001 under the Strategy for Science, Technology, and Innovation. Science and technology along with nanotechnology policies have funded the construction of research centres and the renewing of extant ones.

The six cases are presented in this chapter. I describe their research areas, members, and positions towards nanotechnology. Two cases, Alpha and Beta, are involved in research areas dealing with nanoparticles and biological systems, and host scientists with backgrounds from the three established scientific disciplines of physics, chemistry, and biology. Although monodisciplinary, Gamma tackles the theoretical side of material science and studies the behaviours of specific atoms under certain conditions. Delta, Epsilon, and Omega are engaged in the experimental side of material science and more precisely the growth of nanomaterials, nanolayers, and properties of semiconductors surfaces.

3.2 SCIENCE AND TECHNOLOGY POLICY, AND POLITICAL CONTEXT

3.2.1 Towards a knowledge-based economy

Since its independence in 1921 and over the next four decades, Ireland’s economy was mainly based on agriculture (Cunningham, 2010). Science started to be considered by the government in 1970s through the work of the National Science Council and the National Board for Science and Technology. Through these efforts, Ireland developed areas such as marine and energy but also formed its first biotechnology programme. This period was nevertheless characterised by a lack of coordination between policy and funding. Indeed, before the first European Community Support Framework (1989-1993), the support for science and technology was not appropriate mainly because of low industrial innovation and a national system of innovation which was not developed to a great extent. However, this programme enabled a large range of new initiatives, for instance, Programmes in Advanced Technology, linking university expertise with industry, supporting industry R&D, and mechanisms to improve technological performance of indigenous companies (Department of Jobs, Enterprise and Innovation, 2006).

In the 1990s, Ireland started to invest in the development of a knowledge-based economy (Cunningham, 2010) to improve technology, medical products and procedures, food quality and services (Office of the Chief Scientific Adviser to the Government, 2012). It was a suitable period for Ireland to make some investments as the national and international contexts were in favour of the country (Forfás, 2000). Indeed, Ireland’s gross domestic product (GDP) per capita was growing and equalled Spain, Portugal and Greece until 1992 and then, in 1998, reached and overtook the level of Western Europe (Office of the Chief Scientific Adviser to the Government, 2012). The internal context was further favourable in the late 1990 as the Irish economy was growing and the US and EU economies were also steadily increasing while Asia was recovering from the 1997 crisis (Forfás, 2000).

An important step in science policy in Ireland was initiated under the National Development Plan of 2000-2006 with the foundation of Science Foundation Ireland and the expansion of the Higher Education Programme for Research in Third Level Education (PRTLI – created in 1998). Ireland aimed at investing 2.5% of its GDP on R&D by 2010 (3% is required by the Lisbon Agenda). The main challenges that Ireland faced were as follows: (1) increasing the participation of young people in science (Forfás, 2003, 2005) and the number of people with advanced qualifications, (2) improving the quality and quantity of research, and (3) increasing the outputs of economically relevant knowledge and Ireland's participation at international level.

To build a knowledge-based economy, Ireland had to develop high technology sectors, high-growth and high-productivity activities and, especially, biotechnology and information and communication technology (Forfás, 2000). This decision applied to largely developed higher education and research infrastructures, as well as to link innovation and development at regional, national and enterprise levels. In 2001, the levels of R&D in both industry and the public sectors (including higher education) were 25% below the European Union average and even further below compare to the OECD average (Forfás, 2002).

By being one the most globalised economies in Europe, Ireland faced a rather difficult context which led to a lower growth than expected (Forfás, 2007). In 2002, the information and communication technology (ICT) sector – computer hardware and software – underwent an important slowdown with more than 35,000 job losses. Despite the ICT crisis, Ireland's global economy continued to perform quite well and was considered to be 'established' rather than 'in transition' (Forfás, 2005) and this, until the financial and economic crisis in 2008. During this period of time, the manufacturing sector evolved towards more high-value products and services that needed a greater mobilisation of knowledge, such as the applications of new technologies in the life science, information and communication technology and nanotechnology (Forfás, 2007). Since 2008, Ireland has been facing a rather difficult time with a negative growth of GDP until 2010 (Forfás, 2011).

3.2.2 Development of science and technology from the late 1990s onwards

In a highly competitive international context, science is an economic driver, and from 2000, Ireland has invested in science, and both public and private investments have increased around 14% per year (Cunningham, 2011). Over the nine years from 1998 to 2007, the research outputs of Ireland had doubled while they were levelled for countries such as Germany or France (Forfás and the Higher Education Authority, 2009). This increase was also qualitative, as the quality of Irish publications was above the European Union average since 2004 and reached the OECD level in 2008 (Office of the Chief Scientific Adviser to the Government, 2012). Moreover, all seven Irish universities as well as the Dublin Institute of Technology, Royal College of Surgeons in Ireland and Dublin Institute for Advanced Studies had international publications (Forfás and the Higher Education Authority, 2009). Additionally, Trinity College Dublin and University College Dublin were moving up in the world universities rankings (Forfás and the Higher Education Authority, 2009). Then, 3,500 new academic positions have been added to the seven universities of which half of them were from overseas (Cunningham, 2011). To achieve that increase, several actions and investments were conducted mainly over the previous decade.

In 1999, the Irish Council for Science, Technology and Innovation (ICSTI) created three different task forces. Their tasks were: (1) to commercialise the research that was produced in higher education and public research organisations; (2) to develop modern biotechnology (a sector in which Ireland has been present since the 1970s) – defined as 'an enabling technology that affects a large number of sectors' (Forfás, 2002: 22) and was considered for Ireland a key area for economic growth; and (3) diffusion to the public of science, technology and innovation.

The creation of the task forces was a sign that Ireland was seeking to invest in building a knowledge-based economy. An important investment in this direction was the creation of Science Foundation Ireland (SFI) in 2000. SFI is the major funding agency in Ireland and funds mainly basic research. It receives an envelope that is then distributed through competitive calls for funding. In July 2001, SFI announced its first award of €71 million, which funded principal investigators in the fields of biotechnology, and information and communication technology (Forfás, 2002). Ireland still favoured two particular sectors: biotechnology and ICT. Later, important investments were made under the National Development Programme. This commitment was also made through an increase of the research funding for SFI in the 2003, even though the country was under budgetary constraints (Cunningham, 2011). In 2003, SFI became the third Forfás agency, having previously been a sub-committee. Although nanotechnology is cited for the first time in the Forfás Annual Report of the year 2000, in its funding programme, biotechnology and information technology remained the main technologies to be developed. 'Nano' was cited because of its presence in the EU FP6 as a research topic 'within the food areas of genomics, bio-materials and nano-materials and key technologies for the sustainable use of energy resources and the protection of the environment' (Forfás, 2001: 30).

Ireland was more and more involved at the European level in the negotiations for the Seventh Framework Programmes. Information and communication technology, biotechnology and nanotechnology are priority areas for European research (Forfás, 2005). In order to reach research excellence and to be able to compete internationally, Ireland, as latecomers, developed its focus in the areas that contribute most to the economy. The main weaknesses for Ireland were in higher education, and facilities and equipment available to support research and education. A restructure was necessary to have a better funding system and an internationally competitive science, and to invest in applied research for example health, environment and security (Office of the Chief Scientific Adviser to the Government, 2011).

In 2009, Forfás and the Higher Education Authority published a bibliometric study of the research outputs produced in Ireland (publications, citations, disciplines and institutions). The report shows that, in 2007, Ireland had 0.3 to 0.4% of the total world total publication share, and had increased its production to 33%. By contrast, comparator countries had grown to just 14% (see Table 3.1).

Table 3.1: Comparator countries for Ireland's research outputs in 2007

Country group	Country name	Country group	Country name
G7	Ireland	Other Europe	EU27 group
	USA	Regional	Northern Ireland
	UK		Scotland
Other western Europe	Belgium	Other world	Australia
	Denmark		Brazil
	Finland		China
	Netherlands		India
	Portugal		New Zealand
	Sweden		Singapore
Other Eastern Europe	Czech Republic		South Korea

Source: (Forfás and the Higher Education Authority, 2009: XVI)

The country performs better in some areas more than others such as biological science (0.5%), agriculture (0.6%) and agriculture biotechnology (1.5%). Ireland's share of the world outputs in biological science has almost doubled from 0.33% in 1998 to 0.62% in 2007. Growth in this area has been strong at 35 to 40%, particularly in biotechnology. Indeed, Ireland has moderately increased its share of the world of biotechnology papers while other countries have declined. Moreover, the papers in biotechnology are well cited, with the exception of those published in 2007. The study suggests that some effort should be made in order to produce fewer papers with a greater impact. In this area, UCD performs particularly well.

Ireland shows strong growth in the number of papers published in physics and material sciences (25%), which is 9% greater than the average for comparator countries. This rate of growth in the six years to 2007 is very strong, exceeded only by China (41%) and India (22%). By contrast three quarters of the countries in the comparator group suffered a net loss in their percentage of world share during the same period. Ireland's share of the world total outputs was only 0.30% in 1998, but by 2007 this had increased to 0.45%. In terms of citations, Irish papers in physics and material science are cited to the average rate. Papers published in 2006 are particularly well cited. In physics and material science, University 3 performs well.

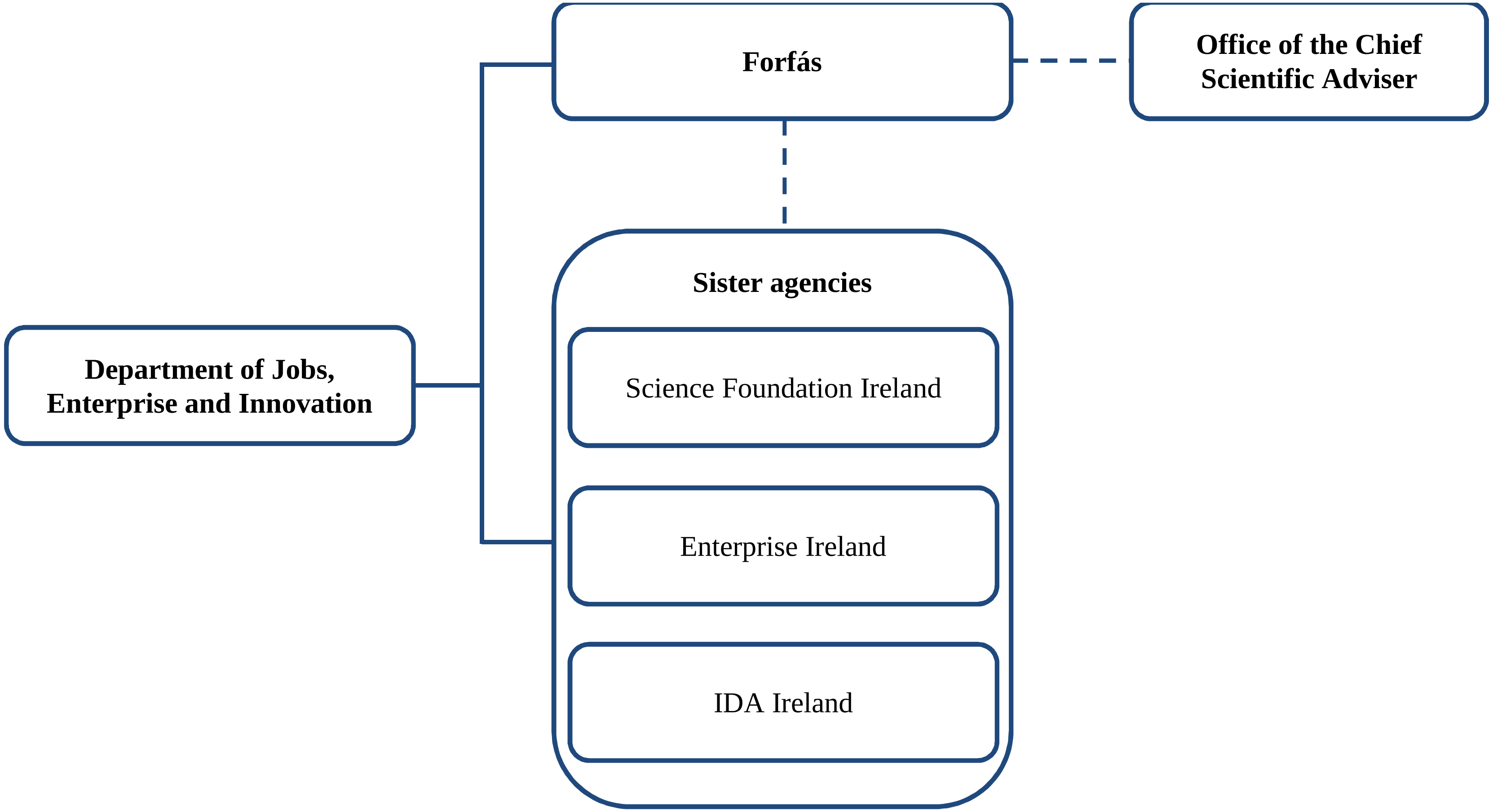
In nanotechnology, the number of papers is low but is consistently increasing. Research outputs over the last ten years have grown to a current high of 0.61% of total world output. This is a research area where Ireland is increasing in terms of research volume. Irish nanotechnology papers produced between 2002 and 2004 are well cited. In general, Irish papers are in the mid-level in terms of numbers of citations. It is important to note that, depending on the classification, the measure of nanotechnology papers can change. Indeed, N&N publications can be published in biology, chemistry, or physics journals.

3.2.3 Development of nanoscience and nanotechnology in Ireland

Under the steering of the Department of Jobs, Enterprise and innovation, different bodies play different roles in the organisation of research in Ireland. First, Forfás, created in 1994, is governmental agency which advises the government on the questions of enterprise, science, technology, and innovation, producing reports to support the government in its choices. Another goal of this agency is to make the roles of the different agencies more coherent and to avoid overlaps (see Figure 3.1). These agencies are the Science Foundation Ireland which mainly funds basic research, Enterprise Ireland which funds application-oriented projects, and IDA Ireland (Industrial Development Agency) which is in charge of the foreign investments in the country. To describe the context in which N&N rose in Ireland and the consequences on research laboratories, the focus is mainly on Forfás, Science Foundation Ireland, and the Office of the Chief Scientific Adviser.

Ireland was pro-active in the development of nanotechnology in the country. Indeed, few countries in Europe put in place a formal strategy that aimed at developing this area; although no countries stayed away from nanotechnology. It is sometimes funded through the usual science and technology routes. The Statement on Nanotechnology (Irish Council for Science, Technology and Innovation, 2004) describes that the development of nanotechnology had been done in three main stages. The first stage, from 1980 to 2000, saw the emergence of a mature nanotool sector and the existence of a nascent nanomaterial sector. Although the report states that the nanomaterial sector is consolidated, and there are a growing number of nanotools and nanomaterial enabled products and processes, it was during the second stage from 1990 to 2010 that Ireland really started to invest and develop N&N. The country spent about €282 million on nanotechnology (basic research, applied research, technology transfer) during the third stage between 2001 and 2009 (Forfás, 2010).

Figure 3.1: Ireland's science and technology system



As there was no strategy for nanotechnology in Ireland until 2010, it is difficult to track the evaluation of the different policy decisions that have been made before the Nanotechnology Commercialisation Framework 2010-2014 was implemented (Forfás, 2010). Moreover, from the late 1990s, Ireland largely invested to develop science. The two are therefore intertwined.

Founded in 2000, Science Foundation Ireland funds projects in basic research, including nanotechnology. The first projects related to nanotechnology, and thus the beginning of nanotechnology from a policy perspective, is related to the creation of SFI. SFI was an important actor in the development of nanotechnology in Ireland as it helped to build a nano-dedicated research centre in University 3. From the scientific side, nanotechnology started earlier, but the funding either came from the FP5 (and FP6 before the funding system really got started), or other calls for projects that enabled research at the nanoscale. It is possible to track the investments that have been made in N&N between 2004 and 2006 with a reclassification of the fields of science and the creation of the N&N category as a sub-field of engineering and technology (Forfás, 2008).

Based on the ‘Statement On Nanotechnology’ (Forfás, 2004), the economic potential of nanotechnology is recognised and re-estimated at €13 million by 2010. Even though nanotechnology can be an opportunity for companies of all sizes in a range of sectors, the ICSTI statement recommends that nanotechnology serves the needs in ICT and healthcare (Forfás, 2004).

From 2005, Forfás has become more pro-active about nanotechnology and Technology Assessment exercise in order to identify investment and policy option for the development of nanotechnology. They are also more specific about the definition of this technology: ‘nanotechnology is the science of the very small and is a collective term involving the manipulation of atoms at the scale of a nanometre’ (Forfás, 2006: 41).

Forfás undertook a pilot Technology Assessment (TA) exercise to identify investment and policy options for the successful development and application of nanotechnology in Ireland. The NanoIreland project was undertaken on behalf of the Department of Enterprise, Trade and Employment (former name of the Department of Jobs, Enterprise and Innovation), and is considered to be an important priority-setting mechanism for research investments. It also provides the basis for establishing clear industrial input into the overall research agenda (Forfás, 2007). Three expert working panels undertook the development of future-oriented scenarios in the area of nano-electronics, nano-biotechnology and nano-materials. The scenarios integrated key scientific, technological, economic, environmental, political, values and social drivers.

The development of N&N in Ireland has been taken to the next level with the order and the publication of the Nanotechnology Commercialisation Framework 2010-2014. This study was undertaken in collaboration with an American company called Lux Research (a venture capitalist company in the Silicon Valley) which specialises in nanotechnology and emerging technologies. Before that, Ireland did not have its own strategy for nanotechnology. Small initiatives had been undertaken, but nothing at a more global and integrative level. Implementing a strategy for N&N in Ireland had an impact on both the policy and science sides. Indeed, different agencies have been impacted by nanotechnology and have interest in funding projects in this area.

3.3 CONTEXT AND RESEARCH QUESTION

N&N in Ireland is a suited context for the research question: Can policy makers influence the emergence of a new scientific discipline? Different initiatives from policy makers have been undertaken with the aim of developing N&N in the country.

Moreover, these initiatives do not only encompass scholarships, but also the construction of facilities dedicated to this area. During the years and through the studies, Ireland has placed N&N as a central area for development involving both research and industry. As a result, despite being a latecomer, Ireland made important investments in the area to become ranked sixth amongst the countries producing outcomes in N&N.

Ireland is a rather small country. Therefore, the delineation of the case is easier, and the identification of the main informants more feasible. In each governmental organisation – advisor bodies or funding agencies – only one delegate was dedicated to N&N. By consequence, this provides better conditions to have more complete data as the one delegate had knowledge of, and access to, most of the information. On the scientific side, the main actors were also easily identifiable, and most were based in Dublin. Therefore, it was possible to construct a full picture of the different disciplines involved in the area, and this is one of the crucial elements of the study. The variety of disciplines is moreover essential in grasping the different dynamics that can occur within the field. Focusing on only one discipline would be harmful in disregarding the cross-disciplinary characteristic (Bassecoulard et al., 2007; Schummer, 2004b) of the technology.

3.4 CASES: SIX RESEARCH TEAMS

This section aims to present the different teams that were selected for data collection. The focus is on research teams since the way in which science is organised in Ireland is close to the UK and the US. Principal investigators are the main component of this model as they are responsible for rising financial resources in order to fund postdoctoral researchers, PhD students, equipment, infrastructures and so on. Therefore, principal investigators are the only members who have recurrent funding as the other members are funded by either a public agency – Irish or European – or a company. In order to sustain their activity, principal investigators have to comply with the schemes that are drawn-up by policy makers. Moreover, this model is dynamic in adapting to environmental changes. Indeed, as teams are smaller, principal investigators are responsible for their research and the sustainability of their activity. This differs from the model that can be found in Germany or France, where one professor has a greater degree of control of what is happening within his department.

3.4.1 Alpha

This case was used in order to undertake the micro-meso analysis and to answer the following research question: How do scientists involved in a scientific area crossing multiple scientific disciplines use multidisciplinary knowledge in order to create a new scientific outcome? The main focus of Alpha's research is on nanotechnology and pharmacology. This stream of research aims at describing the different characteristics of a nanoparticle (for example size and surface area) and its degree of toxicity. This first part falls into the discipline of nanotoxicology. If a nanoparticle is non-toxic, its characteristics can be used for medical purpose. Since these two aspects are the two sides of the same coin, they are grouped together within the same research team. Alpha studies the whole food chain by including research on algae, fish cells, and mammalian cells among which human cells.

Alpha is hosted in a research centre that provides scientists with facilities, and spectroscopy and characterisation instruments, that were built under the Programme for Research in Third-Level Education Cycle 1. When it opened, the research centre hosted six research groups: radiation and environmental science, environmental chemistry, inorganic chemistry, physics of molecular materials, holographic research, and solid state physics. After some reorganisation – such as the reshaping of the physics of molecular materials and solid state physics groups into nanophysics and the solar energy group respectively – Alpha was created in 2008 from the dissolution of the nanophysics group with the aim of increasing the focus on interactions between nanoparticles and biological systems.

Alpha is involved in two different networks. The first is a national consortium, Integrated Nanoscience Platform for Ireland (INSPIRE), which groups together eight members in Republic of Ireland: Trinity College Dublin, University of Limerick, University College Cork, Dublin Institute of Technology, Dublin City University, National University of Ireland Galway, Cork Institute of Technology, University College Dublin, and two members in Northern Ireland: University of Ulster and Queens University of Belfast. This network has funded most of Alpha's equipment as well as all the postdoctoral researchers and PhD students. INSPIRE ended in 2012 and INSPIRE 2 commenced also in 2012. The purpose of this consortium includes the metrology and the study of the toxicity of nanoparticles as well as the regulation and education aspects of it. The second network is NanoImpactNet. This is a European Network for the health and environmental impact of nanomaterials, and is a Coordination and Support Action (CSA) from the EU FP6 and 7. Beyond the study of the toxicity of nanoparticles, Alpha is also involved in the regulation dimensions of nanotechnology.

In 1989, Alpha's team leader graduated from an Irish university in experimental physics. After holding positions in Germany and in Japan in the same area of research, in 1996 he integrated the host university into the physics department. In 2000, he started a managerial position in Alpha's host institute. Since then, he managed different projects from Irish funding agencies – both basic and applied research – as well as European projects. He is seconded by a lecturer from the School of Physics. His PhD was on thin film at the nanoscale. Upon its completion, he worked as a senior researcher in an international laboratory in the department of nanotechnology. His research interests are nanotechnology at large, particularly research on nanomaterials, nanotoxicology, but also the integration of nanotechnology in society.

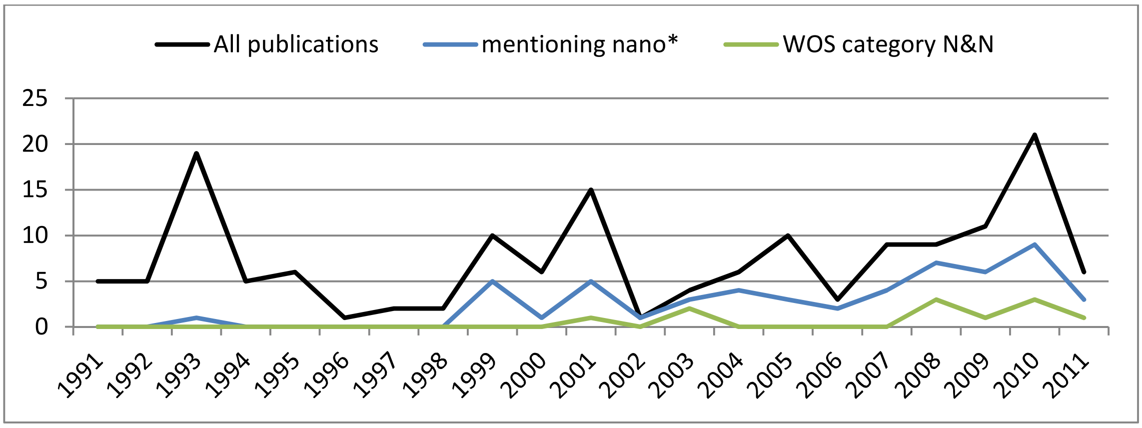
At the beginning of the present study, Alpha was composed of the head of the institute, the head of the laboratory, a lecturer, two postdoctoral researchers, and seven PhD students (one of which was not included in the study as she was abroad while the interviews were conducted). Interviews with Alpha’s members lasted from May 2009 to September 2011 including the two rounds of interviews. Alpha was the first case and was used as a both a comparative and a single case study. Alpha gathered scientists from multiple disciplines including the sub-disciplines of physics, chemistry, or biology of its members. In that sense, Alpha can be considered a multidisciplinary team. The INSPIRE consortium is the main funder of the team in terms of both equipment and scholarships. Indeed, only one PhD student is funded by another funding agency, which is the Environmental Protection Agency. This team is therefore very much in line with the funding scheme of the INSPIRE consortium whose focus is bionanoscience (see Table 3.2).

Table 3.2: Alpha's members

	Position	**Discipline of the highest degree**	**Funding**
Alpha 1.1	Head of the institute	Laser physics	Host university
Alpha 1.2	Head of the laboratory	Physics and chemistry	Host university
Alpha 2.1	Postdoctoral researcher	Applied physics	INSPIRE
Alpha 2.2	Postdoctoral researcher	Molecular biology	INSPIRE
Alpha 3.1	PhD student	Analytical chemistry	INSPIRE
Alpha 3.2	PhD student	Applied chemistry	INSPIRE
Alpha 3.3	PhD student	Biochemistry	INSPIRE
Alpha 3.4	PhD student	Toxicology	INSPIRE
Alpha 3.5	PhD student	Biochemistry	EPA

Looking at the patterns of publication of each team's founder, a change in the focus of their publications is clear. Since 2008, Alpha's foundation year, half of the team's total publications mention the word '*nano*' and count for more than half of its total citations. If 2007 is included – the year during which projects with nanoparticles were conducted, but Alpha was not officially created – the publications mentioning the word '*nano*'increases from 25 to 29 articles. This partial commitment to N&N is explained by the fact that Alpha's leader is also manager of the research centre, and part of his publications includes other domains of research. Moreover, spectroscopy techniques, which, even although used in the N&N, can be used to produce images of cells without necessarily mentioning the word '*nano*' in the publication title. It is worth noticing that only eight articles out of 47 are published in a Web of Science (WOS) N&N journal. It is also interesting to note that Alpha's team leader started to use, at an early stage, '*nano*' in his publications (see Appendix E p.218 for more details).

Figure 3.2: Evolution of Alpha's team leader publications from 1991 to 2011



3.4.2 Beta

Beta's team leader got his PhD in theoretical chemistry from an English university in 1984. He then developed an international career, holding different position in the UK, France, and the US. During these years, he improved his experience of managing research teams and conducting research at the frontier of materials and biology. He is also involved in various expert groups, mostly at European level, for the standardisation of nanotechnology and for the assessment of its risks.

Beta was created from a collaboration between its leader and a postdoctoral student. During a research visit to Sweden, they collaborated with biologists in order to study the interactions between nanoparticles and human cells. As this new stream had been successful in answering a few funding proposals, they decided in 2006 to answer a call for funding from the Irish government that was intended to fund research facilities. This call was organised by the Programme for Research in Third Level Education. Having received a favourable answer from the government, Beta returned to Ireland to start the project. At the beginning of the project, the group was composed of Beta's team leader and the postdoctoral researcher, as well as five other researchers that were working with them in Sweden. As they were tackling a novel area, new methods and protocols had to be built. Researchers of various backgrounds gathered together to tackle these new issues. The team crosses all three main disciplines of physics, chemistry, and biology. Only Beta 1.1 has a salary paid by the host university: all of the other members are on a non-permanent contract based on both national and supranational funding (see Table 3.3).

Beta is also involved in different national and international project such the INSPIRE consortium and NanoImpactNet. Funding comes as much from Ireland as from the Seventh European Framework Programme. Even although Beta's research is close to

Alpha, it does not have the same structure of funding. Indeed, Beta's funding is more diverse, and includes financial resources from the INSPIRE consortium, Irish funding agencies, and the European Commission. I did not interview all members as theoretical saturation was reached with these members whom I interviewed from March 2011 to December 2011. This timespan includes the two rounds of interviews. I favoured postdoctoral researchers as they have more perspective on their activity. I however completed the data with the interview of a PhD student.

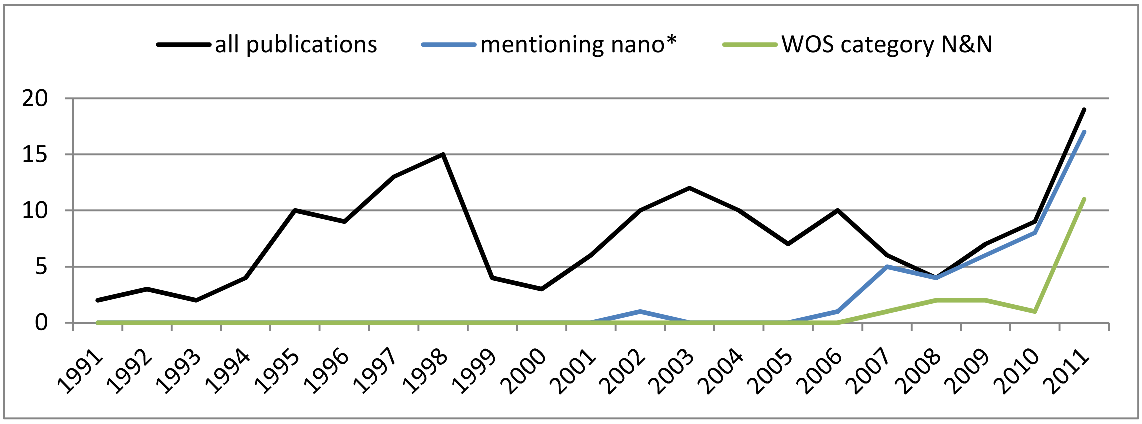
Table 3.3: Beta's members

	Position	Discipline of the highest degree	Funding
Beta 1.1	Head of the Centre	Chemistry and mathematics	University 2
Beta 2.1	Strategic manager	Chemistry	EU FP7
Beta 2.2	Postdoctoral researcher	Molecular biology	EPA
Beta 2.3	Postdoctoral researcher	General biology	SFI
Beta 2.4	Postdoctoral researcher	Theoretical high energy Physics	IRCSET*
Beta 2.5	Postdoctoral researcher	pharmaceutical Biotechnology	EU FP7
Beta 3.1	PhD student	chemical engineering	EU FP7

* Irish Research Council for Science Engineering and Technology

Since Beta's foundation in 2007, 40 out of 45 of its publication output have mentioned the word 'nano' and represent almost the total sum of its citations. Beta has a strong use of the word in the titles and/or in the abstracts of its publications. Beta demonstrates commitment to this new area. However, only 17 articles are classified as N&N by the WOS (see Appendix E p.218 for more details). Moreover, the articles published outside of the WOS N&N category are on average more cited than the ones published within this category. From the use of the word '*nano*' in his publications, Beta's team leader is strongly committed to N&N from the creation of the laboratory. Indeed, since 2007, almost all his publications contain the word in the title and/or the abstract (see Figure 3.3).

Figure 3.3: Evolution of Beta's team leader publications from 1991 to 2011



3.4.3 Gamma

Gamma is hosted in the biggest research centre dedicated to nanomaterials and nanodevices. The research centre groups 250 researchers, among them are 18 PIs, postdoctoral researchers, PhD students and technicians. This number also includes the technicians in charge of the different equipment and administrative staff. Gamma's team leader received his PhD from an English university in theoretical physics in 1999. After being an assistant researcher in an American university for two years, he integrated into the physics department of his current university in 2001, and became a permanent member in 2006. Since then, he developed his research activity of computational physics and in 2007 joined the research centre dedicated to N&N of his university as a principal investigator.

Gamma started in 2002 as a computational spintronics group. The team's aim is to develop computational methods for simulating small-scale devices and novel materials.

One goal of the main project is to develop and improve a computational tool for calculating electronic transport in nanoscale devices. Gamma’s team leader receives funding mainly from the FP7, SFI and IRCSET. Indeed, its funding structure is equally derived from national and non-national sources, ensuring that its activity is not entirely dependent on the country’s situation. In that sense, it is interesting to notice that a postdoctoral researcher is funded by King Abdullah University of Science and Technology. His team is the biggest in the research centre with six postdoctoral researchers, of which five were interviewed; and ten PhD students, among whom three were interviewed (see Table 3.4). The interviews lasted from May 2011 to December 2011 including the two rounds of interviews.

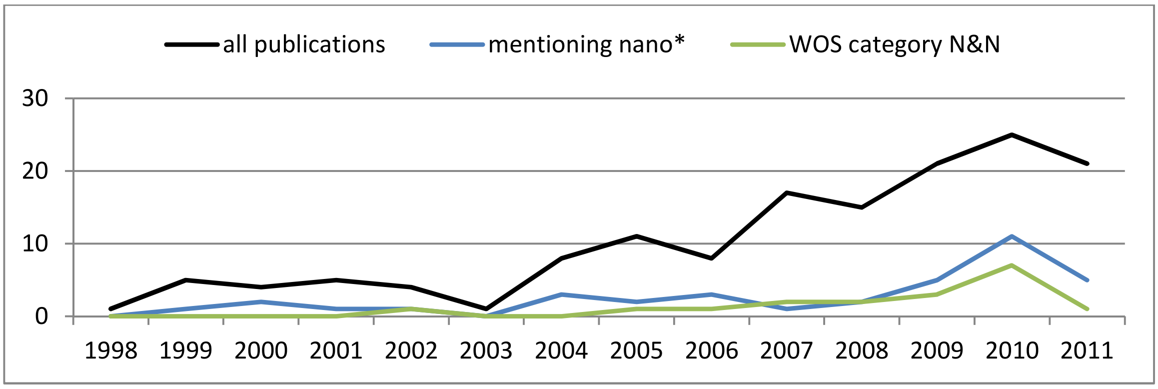
Table 3.4: Gamma's members

	Position	Discipline of the highest degree	Funding
Gamma 1.1	Head of the laboratory	Theoretical physics	University 3
Gamma 2.1	Postdoctoral researcher	Theoretical physics	SFI
Gamma 2.2	Postdoctoral researcher	Theoretical physics	SFI
Gamma 2.3	Postdoctoral researcher	Theoretical physics	EU FP7
Gamma 2.4	Postdoctoral researcher	Computational physics	EU FP7
Gamma 2.5	Postdoctoral researcher	Condensed matter	EU FP7
Gamma 2.6	Postdoctoral researcher	Computational physics	KAUST*
Gamma 3.1	PhD student	Theoretical physics	EU FP7
Gamma 3.2	PhD student	Theoretical physics	SFI
Gamma 3.3	PhD student	General physics	IRCSET

*King Abdullah University of Science and Technology (Saudi Arabia)

Gamma’s leader has been using the word ‘*nano*’in his publications since his PhD studies in 1999. Overall, since the creation of the team in 2006, 27 articles have included the word ‘*nano*’ either in the title, abstract, keywords, or all three; and 16 of them are classified by WOS as ‘nanoscience and nanotechnology’. Gamma’s pattern of publications has not changed after joining the research centre dedicated to nanomaterial and nanodevices. Despite this, about a quarter of the team's publications contained the word '*nano*', and even less fall into the WOS 'nanoscience and nanotechnology' category. For its leader, joining the research centre in 2006 was more a means to start a team and to develop his research than a strong voluntary engagement with the area of N&N. This is consistent with the idea that N&N is a trend that is too broad to be scientifically relevant to its area of research, as well as Gamma's self-perception as computational scientists, rather than belonging to a new breed of scientists (see Figure 3.4 and Appendix E p.218 for more details).

Figure 3.4: Evolution of Gamma's team leader publications from 1998 to 2011



3.4.4 Delta

Delta, Epsilon, and Omega are hosted by the same university. This university does not have a laboratory or a research centre dedicated to N&N, and only a few staff members are working in this area. However, through different national funding programme, such as PRTLI Cycle 5, the university is gradually moving toward having some facilities for nanotechnology. So far, nanotechnology has only been present in the university through different research groups and researchers whose area falls into the nanotechnology category and who are working on a single-project basis. N&N can appear in different research areas without being the core characteristic of a centre within the university. Here, N&N is considered as crossing the different areas of research but not as an established science or a single technology. The university has not, to this point, structured its research priorities specifically around nanotechnology. It has instead focused on areas such as sensors, plasma science and technology such as cellular biotechnology and so on. However, nanoscience underpins many of these aspects. Within the frame of the PRTLI cycle 5, the building will be developed with a space dedicated to nanotechnology. This cycle will focus more on enhancing and developing the existing infrastructure than on building a new facility. So, the university is gradually moving towards nanotechnology with having facilities dedicated to nanotechnology.

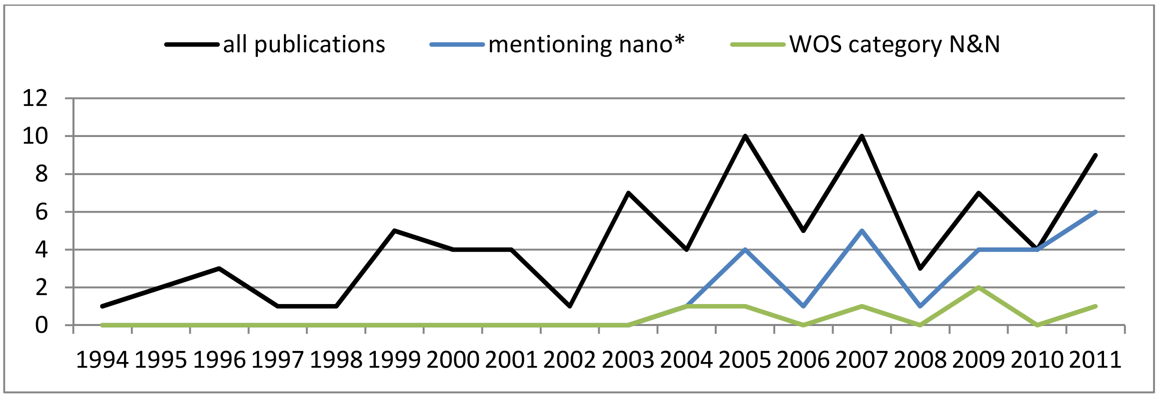
Delta team focuses on the growth of nanostructured semiconductor materials and the characterisation of such materials using electron microscopy, electrical techniques and optical spectroscopy. The group studies the properties of semiconductor materials used in the manufacture of electronic and optoelectronic devices, as well as in other applications. Delta is made up five members, including the team leader. I interviewed them from July 2011 to August 2011 including the two rounds of interviews. Delta's team leader graduated from the host university and, after a postdoctoral position in an Irish research centre, he returned to the university to start a group on the growth and study of semi-conductor materials. He has spent the majority his career in the university, progressively climbing the hierarchy until appointment as head of the physics department. All members have a degree related to physics, although two of them have a broader scope towards biology and chemistry. Only national funding is mobilised for the PhD student scholarships, and of the most of the collaborators are based in Ireland (see Table 3.5).

Table 3.5: Delta's members

	Position	Discipline of the highest degree	Funding
Delta 1.1	Head of the team	Applied physics	University 4
Delta 3.1	PhD student	Biophysics	IRCSET
Delta 3.2	PhD student	Applied physics	SFI
Delta 3.3	PhD student	Applied physics	SFI
Delta 3.4	PhD student	Physics and chemistry	SFI

Delta's team leader started to use the word '*nano*' from 2004, and increasingly so until 2011. Even although Delta's team leader claims to have switched his attention to N&N in the very late 1990s, the change in his publications are especially clear from 2004, when Ireland started to become more proactive in the area. Although more than a third (26 articles) of Delta's publications mention the word '*nano*', only six are classified as 'nanoscience and nanotechnology' by the WOS. Moreover, the articles classified in this WOS category are proportionally less cited than those not classified as N&N. From 2004, Delta 1.1 has been increasingly using the word '*nano*' in his publications (see Figure 3.5 and Appendix E p.218 for more details).

Figure 3.5: Evolution of Delta's team leader publications from 1994 to 2011



3.4.5 Epsilon

Epsilon is part of the same group as Delta. This is an experimental group that focuses on material surfaces and the interactions between the different layers. This area of research overlaps both chemistry and physics, and deals with the layers at nanoscale. Epsilon's team leader graduated in 1983 from a Northern Irish university in chemistry. Then, after a two year postdoctoral research in IBM, he integrated the host university in the physics department. He also has international experience, having spent a year visiting a university in Germany, and another in the US.

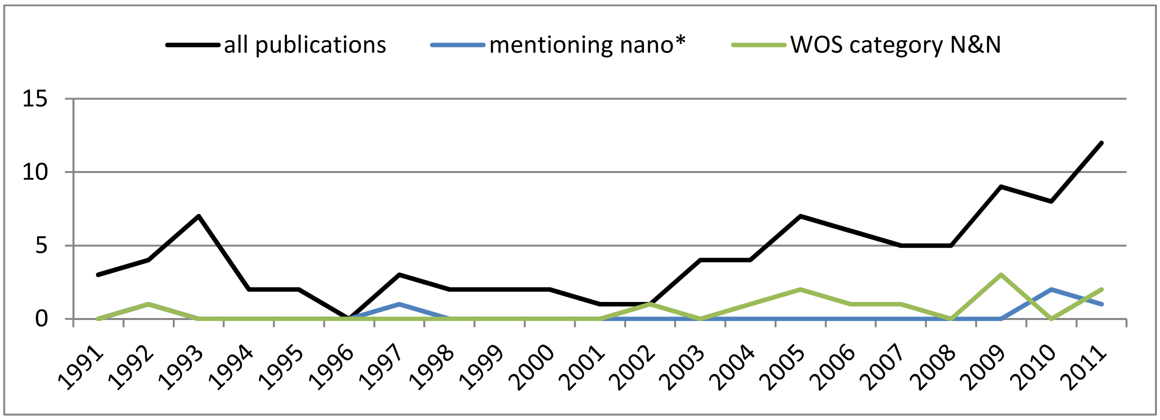
Straddling these two disciplines, the PhD students and the postdoctoral researchers have knowledge in both areas. Moreover, their backgrounds are not strictly from one discipline (see Table 3.6: Epsilon's members). While tackling basic scientific issues, the group also collaborates with industrial partners such as IBM which enables financial incomes for scholarships. Even although, at the time of the study, Epsilon benefited from funding from national agencies, the decrease of funding in Ireland crisis led Epsilon's team leader to broaden the scope of the potential financial resources. Epsilon is made up of one team leader, a postdoctoral researcher and three PhD students. I conducted the interviews from July 2011 to December 2011. One PhD student was not available at the time for the study.

Table 3.6: Epsilon's members

	Position	**Discipline of the highest degree**	**Funding**
Epsilon 1.1	Head of the team	Chemistry	University 4
Epsilon 2.1	Postdoctoral researcher	Physics and chemistry	IRCSET
Epsilon 3.1	PhD student	Applied physics	SFI
Epsilon 3.2	PhD student	Technology physics	SFI

Even although they conduct research at the nanoscale which is relevant for the semiconductor industry, Epsilon barely mentions the word '*nano*' in its publication. Indeed, only three out of the 66 articles that have been published between 1991 and 2011 mention '*nano*' in title and/or the abstract. It is however interesting to note that 11 of its publications fall in to N&N WOS category. Therefore, the constructed WOS category of N&N encompasses part of the research of the group, although the group does not voluntarily commit to the area (see Figure 3.6 and Appendix E p.218 for more details).

Figure 3.6: Evolution of Epsilon's team leader publications from 1991 to 2011



3.4.6 Omega

Omega is the third group that is hosted by the same university as Delta and Epsilon. Its research focuses on the study of the electrical and chemical properties of semiconductor surfaces. Omega's team leader received his PhD in 1985 in solid state physics from a US university. He then held different positions in England and Wales before coming to Ireland and getting a permanent position at his current university.

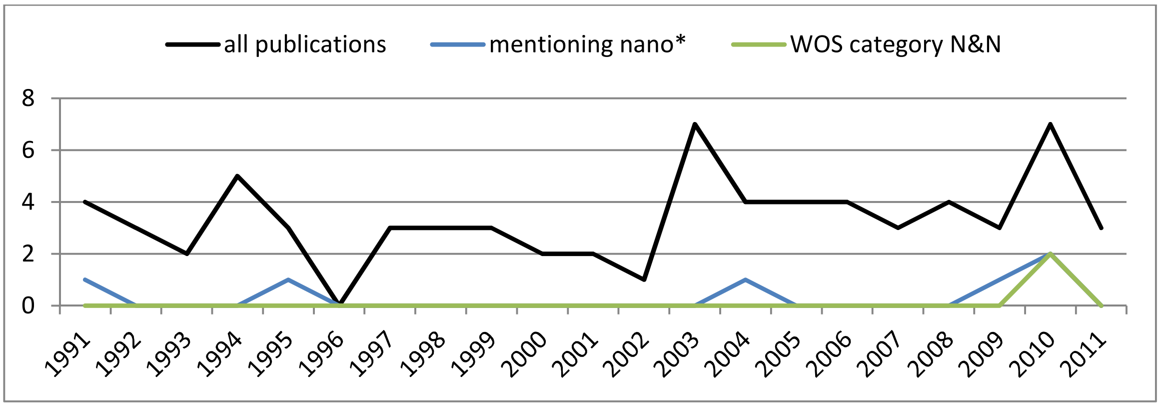
Like Epsilon, the group's research area overlaps both physics and chemistry. It is for this reason that a PhD student, Omega 3.2, has a postgraduate degree in applied chemistry. The postdoctoral researcher also did his PhD mobilising both physics and chemistry. Researchers in this group are mainly funded by SFI except one who benefited from an IRCSET scholarship (see Table 3.7). I conducted the interviewed with Omega’s members from August 2011 to December 2011.

Table 3.7: Omega's members

	Position	**Discipline of the highest degree**	**Funding**
Omega 1.1	Head of the team	Physics	University 4
Omega 2.1	Postdoctoral researcher	Physics and chemistry	SFI
Omega 3.1	PhD student	Physics	SFI
Omega 3.2	PhD student	Applied chemistry	SFI
Omega 3.3	PhD student	Physics	IRCSET

Omega’s team leader has used the word ‘*nano*’ only six times in his articles since 1975. However, nine articles are considered by the WOS as falling into the N&N category. Since the centre was created in 1999, four articles contain the word ‘*nano*’, and six fall into the WOS N&N category. Among the articles that mention the word ‘*nano*’, none follow a specific trend: the articles were published in 1991, 1995, 2004, 2009 and 2010. Moreover, most of the journals that are targeted do not fall into the WOS ‘nanoscience and nanotechnology’ category (see Figure 3.7 and Appendix E p.218 for more details).

Figure 3.7: Evolution of Omega's team leader publications from 1991 to 2011



3.5 CONCLUSION

The study of research teams in Ireland represents a well suited fieldwork for the research question. Indeed, the country has largely invested in this technology with new funding schemes across funding agencies, budget lines, creation of new research centres, and so on. Moreover, this has been ingrained in the science and technology policy, for example in studies such as Ireland's Nanotechnology Commercialisation Framework 2010-2014 (Forfás, 2010). By funding both the infrastructure with equipment and the scholarships, policy makers provide the favourable conditions for the development of this technology.

Then, the functioning of science is highly dependent on external financial resources with one principal investigator remunerated by a university and the other members – postdoctoral researchers and PhD students – paid by external funding. In this way, their research activity has to follow the call for funding and to answer the requirements expressed by policy makers. Moreover, teams are small which makes them more flexible to adapt to environmental changes. This whole context therefore represents a fruitful opportunity to deepen understanding of the extent to which the spaces created by policy makers trigger the emergence of a new discipline.

The teams that were selected conduct research within the main stream established by the Irish government: material science and bionanoscience. None of the team leaders have a background in biology, yet two of them have moved to a research area related to bio-systems. Half of the teams were constituted during the first wave of funding in Ireland, whilst the other half benefitted from nano-dedicated funding. Teams that conduct research related to bio-systems have members from multiple backgrounds including biology. One team, Omega is considered as multidisciplinary as one member has a primary degree in chemistry (see Table 3.8).

Table 3.8: Description of the research teams

	ALPHA	**BETA**	**GAMMA**	**DELTA**	**EPSILON**	**OMEGA**	**TOTAL**
University	University 1	University 2	University 3	University 4	University 4	University 4	
Areas of the activity	Nanotoxicology, pharmacology	Nanobiology, nanotoxicology	Computational physics	Material science	Material science	Material science	
Purpose of the research team	Toxicity and behaviours of nanoparticles within human, mammalian, fish cells and algae	Behaviours and interactions of nanoparticles with biological systems for medical purpose	Properties of nanoparticles through computational simulation for theory and computational tools	Semiconductors growth and nanostructures through characterisation techniques	Chemical interactions on semiconductors surfaces for their electrical properties	Electronic, chemical and structural properties of semiconductor surfaces by using radiation sources	
Type of research	Experimental	Experimental	Both simulation and theoretical work	Experimental	Experimental	Experimental	
Environment	Multidisciplinary	Multidisciplinary	Monodisciplinary	Monodisciplinary	Monodisciplinary	Multidisciplinary	
Founding year	2008	2007	2006	1999	1999	1999	
PhD of the team leaders (year)	- Experimental physics (1989) - Experimental physics (2001)	- Theoretical chemistry (1984) - Chemistry (2002)	Theoretical physics (1999)	Solid state physics (1996)	Surface physics (1983)	Solid state physics (1985)	
Data collection	From May 2009 to September 2011	From March 2011 to December 2011	From May 2011 to December 2011	From July 2011 to August 2011	From July 2011 to December 2011	From August 2011 to December 2011	
Professor	1*	1*	1*		1*		4
Lecturer	1*			1*		1*	3
Postdocs	2	5 (of which 1*)	6		1	1	14
Ph.D. students	6	1	3	3	2	3	18
Individuals	10	7	10	4	4	5	40

*Team leader

Chapter 4.

Powerful actors and the emergence of a new institutional logic: A boundary story

4.1 INTRODUCTION

This chapter deals with the macro level of analysis with the interplays between science and politics. It focused the first –sub-research question of the study: To what extent can powerful actors, such as funding agencies, trigger institutional change by influencing the reconfiguration of the boundaries of science? The interactions between these two spheres are a long stand debate which many scholars have dealt with. Weber (1917, 1919/1959) describes these domains as two different professions and vocations that must not permeate one another; in particular, politics must not permeate science. However, science, technology and society (STS) studies show that these two domains are not as separate as Weber would have liked them to be. In *Leviathan and the Air-Pump*, Shapin and Shaffer (1985) show that the construction of scientific facts is not independent from political influences. Latour (1991) pursues this argument by showing that the environment can either enable or hinder the construction of scientific facts. Science isolated from politics exists only within laboratories, as the role of scientists is also to convince people and to secure funding (Latour & Woolgar, 1979; Latour, 1987). Jasanoff (1987) describes the demarcation between the two domains as necessary but a grey area within which the authority and integrity of science is put at stake when scientists are asked to participate in policy making. In a similar vein, Kinchy and Kleinmann (2003) show that the boundary that separates the two spheres is contingent on the political context. An example is given by Oreskes (2003), who shows that a military programme can provide scientists with favourable conditions for basic research. Then, political decisions can trigger contestations when the scientific ethos is put at stake (Slayton, 2007). Finally, studies of scientific and intellectual movements (Frickel & Gross, 2005; Jacobs & Frickel, 2009), and of boundary work (Gieryn, 1983, 1995), theorise how scientists create and maintain boundaries between their own activities and non-scientific activities such as state, religion, and pseudo or deviant science. Both of these streams of work adopt an inner perspective that tends to emphasise how scientists rule out non-scientific actors from what they consider science. However, external actors can trigger change (Leblebici, Salancik, Copay, & King, 1991); this is most likely when they are powerful (Pache & Santos, 2010), as in the cases of regulatory authorities (Holm, 1995) and funding agencies (Ruef & Scott, 1998).

Here, we[1] are interested in answering the following research question: to what extent can powerful actors, such as funding agencies, trigger institutional change by influencing the reconfiguration of the boundaries of science? To deepen the understanding of how boundaries between science and policy are renegotiated and reshaped, we applied a composite-boundary framework (Hernes, 2004a, 2004b) to clarify the dynamics of the physical, social and mental boundaries during the process of institutional change. These three types of boundary relate to the three institutional pillars described in new institutionalism (Scott, 2008). The three boundaries are at the core of institutional logics (Thornton et al., 2012; Thornton & Ocasio, 2008) as they are

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[1] The pronoun ‘we’ is used in order to show the collaborative nature of this section

constitutive of the material and symbolic elements of a logic. In this way, we follow Swan, Bresnen, Robertson, Newell, and Dopson (2010) by using this meta-frame of institutional logics in order to clarify the complexity of the relationships between science and policy (Vermeulen et al., 2007).

Thornton and Ocasio (1999: 804) define institutional logics as ‘the socially constructed, historical patterns of material practices, assumptions, values, beliefs, and rules by which individuals produce and reproduce their material subsistence, organize time and space, and provide meaning to their social reality’. Institutional change occurs when the practices and beliefs associated with a dominant logic are replaced by those of a new logic (Friedland & Alford, 1991). Although institutional change does not merely happen through one logic replacing another (Smith-Doerr, 2005), the imbroglio of multiple institutional logics has largely been overlooked (Lounsbury, 2007; Purdy & Gray, 2009; Smith-Doerr, 2005; Swan et al., 2010). Applying this to our study, we focus on understanding how a logic promoted by policy makers can impact the production of knowledge and the emergence of a new discipline. As both political and scientific actors were involved during the inception phase (Granqvist & Laurila, 2011; Grodal, 2010), the field of nanoscience and nanotechnology (N&N) – the manipulation of particles at the nanoscale, in the range of 1 to 100 nanometres (one billionth of a metre) – provides a fruitful context to deepen the understanding of the competition and entanglement of an institutionalised logic and a new logic (Seo & Creed, 2002).

Through a qualitative and comparative research design, we explored two communities: policy makers who promote multidisciplinary, applied science through their funding schemes; and scientists who conduct research at the nanoscale. First, the logic promoted by policy makers did not have the same impact on all types of boundary. Indeed, while some laboratories adopted a multidisciplinary structure, with scientists of multiple backgrounds conducting research together, the socialisation and the diffusion of the knowledge produced were still discipline-based. Scientific conferences and journals leaned less towards multidisciplinary and application-oriented research. Second, we show that the logic promoted by powerful actors, although financially attractive, was not mobilised by all scientists – and that its rejection was, in some cases, a political claim.

By using a composite-boundary framework to look at the emergence of a new way of producing knowledge, we contribute to the institutional-logics perspective by showing that multiple logics coexist; we do this by decoupling their physical, social, and mental elements. In our case, while the physical boundaries are ruled by the new logic, the social and mental boundaries are still, to a certain extent, embedded in the old way of producing knowledge. Then, we contribute to institutional change by describing that powerful actors – such as policy makers, working through funding agencies – can have a greater impact on the physical elements of an institutional logic than on the symbolic ones. In this way, while the physical boundaries might show an institutional change at the macro level, the situation may be different at the micro level. We then discuss the concept of institutional inertia to describe the different paces at which the boundaries move during an emergence phase, leading to a decoupling between the physical, social and mental structures of the organisation.

We describe in the following section the dynamics between two logics during an institutional change, and then the extent to which using a composite-boundary framework can improve our understanding of the phenomenon. We go on to present the research design, the general context in which the study took place, and how data were analysed. We then detail our findings, in three sub-sections. Finally, we discuss our contribution to institutional logics and institutional change.

4.2 THEORETICAL FRAMEWORK

4.2.1 Emergence of new logics

The complexity of the environment in terms of policies, regulation and rapid technological evolution has made institutional change and the way organisations adapt to these changes a central issue for organisation studies (Greenwood & Hinings, 1996). Seo and Creed (2002) describe institutional change as the results of a dialectical process between embeddedness and agency, during which different logics compete. Individual agency – or ‘praxis’, in Seo and Creed’s (2002) words – is embedded in a multitude of institutional orders that bear different values, beliefs, identities and so on; these can make tensions emerge, and in some cases be a source of change. Institutional logics provide a suitable concept with which to study this phenomenon and the tensions that can occur between the multiple institutional levels. The institutional-logics perspective is a meta-framework of analysis (Thornton et al., 2012) that reconciles the determinist view of institutions (DiMaggio & Powell, 1983; Meyer & Rowan, 1977) with a more micro and process approach (Zucker, 1977, 1991). In other words, it provides a link between embeddedness and praxis (Friedland & Alford, 1991; Thornton & Ocasio, 2008).

Institutional change remains understudied (Lounsbury, 2007; Purdy & Gray, 2009), but the literature provides different views of this complex phenomenon. Institutional change is a process of varying length, during which logics compete until the new one either succeeds (Thornton & Ocasio, 1999) or fails to become dominant (Vermeulen et al., 2007). In some cases, a third logic emerges from a hybridisation of the previously competing logics (Thornton et al., 2005). However, it would be oversimplifying the situation to argue that a new logic merely replaces – or fails to replace – an old one (Smith-Doerr, 2005), and that the field reorganises around the logic that became dominant (Hoffman, 1999). Indeed, Pache and Santos (2012) show that organisations entering a field can use elements from both logics in order to increase their legitimacy. Reay & Hinings (2009) argue that competing logics can coexist through collaborative relationships. Goodrick and Reay (2011) describe how multiple logics can influence individuals in a field and in their work. These different studies show not only that the imbroglio of logics involves the reconstruction of both the material and symbolic elements that constitute a logic (Friedland & Alford, 1991; Thornton et al., 2012), but also that various actors are involved in this process.

To better understand institutional change, it is important to study not only the adoption and diffusion of new practices, beliefs, identities and so on, but also which actors promote the new logic both within and outside the organisation (Pache & Santos, 2010). Indeed, even though an external shock is likely to trigger an institutional change (Leblebici et al., 1991), the adoption of the new logic can find resistance from internal actors (Marquis & Lounsbury, 2007). Building on Oliver's (1991) work, Pache and Santos (2010) argue that we must go beyond actors being passive to change (DiMaggio & Powell, 1983), by considering both the change and the organisational response. Indeed, even though powerful actors such as regulatory authorities (Holm, 1995) or major funders (Ruef & Scott, 1998) are likely to trigger an institutional change, the adoption of the new logic also depends on its representation within organisations. If a new logic is adopted, structure, identity and meaning within organisations and across the field will be impacted.

4.2.2 A composite-boundary perspective on logic emergence

Boundaries between institutional orders are fluid and can be analysed in materials and symbolic practices (Friedland & Alford, 1991). To deepen the understanding of the dynamics during an institutional change, we chose a composite-boundary framework

(Hernes & Paulsen, 2003; Hernes, 2003, 2004a, 2004b) as it allows both the material and symbolic elements of institutional logics to be taken into account and disentangled (Thornton & Ocasio, 1999), through the focus on physical, social and mental boundaries. For each type of boundary, emergence arises from a need to make a distinction between the organisation and its environment by emphasising the similarities and differences (Zerubavel, 1993, 1996) of what is included and what is excluded (Lamont & Molnár, 2002). Physical boundaries comprise more than just tangible entities, such as infrastructures; they also include who is granted access, rules, distribution of roles and resources, etc. They relate not only to the material aspects of an institutional logic – such as the tangible infrastructure of an organisation – but also to the practices that can be modified under a new logic (Lounsbury & Crumley, 2007; Lounsbury, 2002).

Social boundaries refer to those between individuals – the demarcation between members and non-members of an organisation – and allow one organisation to be differentiated from others. Moreover, social boundaries go beyond the organisation in terms of professional norms and work ethics (Hernes, 2004a). As individuals' and organisations' identities are founded by institutional logics (Thornton & Ocasio, 1999), the construct of social boundaries is important in understanding both institutional change (Lok, 2010) and how individuals modify their identity in order to face multiple logics (Battilana & Dorado, 2010). Mental boundaries consist of the shared meaning necessary for collective action (Weick, 1979), and of the way in which individuals make sense of their environment (Weick, 1995a). At the field level, shared meaning is also essential as it enables a field both to emerge (Grodal, 2007, 2010) and to function (Porac, Thomas, & Baden-Fuller, 1989; Porac et al., 2011, 1995).

Our research question focuses on the extent to which powerful actors, such as funding agencies, can trigger institutional change by influencing the reconfiguration of the boundaries of science. To sum up, we follow Swan et al. (2010) by using the institutional-logics perspective in order to study the change that occurs in knowledge production, focusing on the extent to which funding agencies trigger an institutional change within a field by promoting a new logic. We also answer the calls to deepen the understanding of the dynamics between logics (Lounsbury, 2007; Purdy & Gray, 2009; Smith-Doerr, 2005; Swan et al., 2010) that happen during this peculiar process.

4.3 METHODOLOGY

4.3.1 Fieldwork of N&N

In order to answer our research question, we used a comparative case-study research design (Eisenhardt, 1989; Eisenhardt & Graebner, 2007; Yin, 2009), looking at six teams in order to understand how these complex processes evolve over time. By doing so, we focus on how a similar external cause unfolds in different institutional contexts (Greenwood & Hinings, 1996; Seo & Creed, 2002). All teams conduct research in N&N, in order to understand the properties of particles at the nanoscale (Smalley, 2001), and to make new devices (Bhat, 2005). The field of N&N is appropriate to our study as this area is characterised by the involvement of multiple scientific disciplines – such as applied physics, materials science, physical chemistry, physics of condensed matter, biochemistry and molecular biology, and polymer science and engineering (Heinze, Shapira, & Kuhlmann, 2007). None of these sub-disciplines is independent, and overlaps exist between them (Meyer, 2001). Moreover, physics and chemistry are the main parent disciplines of this emergent area (Bassecoulard et al., 2007). This multidisciplinarity is particularly relevant to understanding whether scientists embedded in multiple existing scientific disciplines (Frickel & Gross, 2005) – or institutional orders – will adopt a new logic intended to make them converge to form a new discipline. Different interpretations can be made of the changes, as there are as yet neither established standards and properly shared definitions nor established patterns of actions (Aldrich & Fiol, 1994). Moreover, N&N has benefited from massive funding over the past decades; this has been mainly focused on a particular area (e.g. materials science), but has also impacted bio-related research (Roco, 2003, 2005). Scientific programmes and their implementation through funding agencies are an important factor in the birth of a new discipline, as financial support is a condition for a discipline to emerge (Frickel & Gross, 2005) and scientists have become very dependent on external financial resources (Laudel, 2006a, 2006b).

4.3.2 Research setting and description of the cases

This study was conducted in the Republic of Ireland. This country is suited for the study for three main reasons. First, as Ireland is quite a small and geographically bounded country, actors are easily identifiable. This enabled the authors to gain a fair picture of the area of N&N and of the different actors – scientists and their teams, policy makers and funding agencies – involved in this area. Second, strong scientific and technology policies (STPs) and N&N programmes have enabled the research infrastructure to be developed across the country. The level of funding is now in line with that in leading countries, such as Germany (Forfás, 2011). Moreover, in terms of publication and patent rankings, Ireland has had an increasing trajectory of N&N publications and is among the main European countries that together produce over 60% of the publications in N&N in the Science Citation Index (Heinze, 2004). Third, Ireland has heavily invested in science since the late 1990s, with the number of proactive STPs increasing since the creation of the main funding agency – Science Foundation Ireland – in 2000. Although STPs and N&N policies are two separate actions undertaken by the government, they are largely intertwined. These two types of funding – whether or not directly dedicated to N&N – enable scientists both to build infrastructure and to offer postdoctoral and PhD scholarships.

The research teams studied – anonymised as Alpha, Beta, Gamma, Delta, Epsilon and Omega – meet three main criteria. First, they work in the field of N&N. As there is no single standard definition of this, the definition adopted by an author can impact the delineation of the research. Moreover, the multidisciplinary of this area does not facilitate the definition of its boundaries (Leydesdorff & Wagner, 2009). The range-based definition (i.e. 1 to 100 nanometres – one billionth of a metre) is more-or-less accepted (Bassecoulard et al., 2007). However, it does not represent a sufficient criterion, as some other activities have been relabelled ‘nano’ in order to make them more attractive (Granqvist et al., 2012; Grodal, 2007, 2010). Research teams were therefore selected on the basis of the journals in which they publish and their classification as N&N in the Thomson Reuters Web of Science (WOS).

Second, their parent disciplines relate to N&N. We acknowledge that our selected cases do not cover all of N&N’s parent disciplines. However, the activities of four out of six teams (Gamma, Delta, Epsilon and Omega) are related to materials science, and those of the other two teams (Alpha and Beta) to nanotechnology and biological systems. These areas represent two large sectors, as the former is related to making electronic devices, coatings, chips and so on, and the latter to studying the toxicity of nanoparticles, the making of new drugs, new medical devices, etc. These two sectors are actively fostered in Ireland.

Third, they are involved in N&N education. Three of the six research teams (Alpha, Beta and Gamma) benefit from an N&N graduate teaching programme at their local university. This shows not only that N&N is undertaken at a research level but also that it has permeated education. Involvement in education shows that the universities are willing to develop N&N, and have invested in building new programmes or have modified existing ones. Although they did not meet this last criterion, Delta, Epsilon and Omega were included in the study for two reasons. First, they all belong to a university that benefited from public funding, building two research centres, one dedicated to plasma science and technology research, and the other to sensor research. Both types of research are conducted at the nanoscale. Second, none of their team leaders decided to engage in creating a laboratory that would be marketed as N&N. So these cases present an opportunity to enrich our understanding of boundary creation in a context characterised by ambiguity, and to overcome the bias of not including the perception of actors who have the capability to claim their membership of the emerging area, but choose not to do so (Granqvist et al., 2012).

Then, four of the six research teams studied are involved in the discipline of materials science. Gamma is part of an important research centre dedicated to N&N, and tackles the theoretical and computational side of materials science by developing a code that aims to predict the behaviour of a nanoparticle under certain conditions. The team is made up of postdoctoral researchers and PhD students who focus on different-but-complementary aspects such as improving the codes, studying specific nanoparticles, and doing ‘pen and paper’ work to make theoretical contributions. Delta, Epsilon and Omega have some similarities as they are involved in the experimental side of this discipline. Although all their research has potential application to the semiconductor industry, they can be differentiated by the techniques they are using and the goal of their research. While Delta focuses on the growth of semiconductor materials, Epsilon and Omega study semiconductor surfaces. Moreover, they are all three hosted by centres that do not advertise themselves as N&N. Although belonging to the same university, these three cases have been treated separately in order to allow idiosyncrasies to emerge, as well as to enrich the theoretical construction (Eisenhardt, 1989, 1991).

Alpha and Beta are involved in a more recent area of research, namely the study of interaction between nanoparticles and biological systems. They both market themselves as ‘nano’. Alpha studies the toxicology of nanoparticles over the whole food chain from mammalian (including human) cells to fish cells and algae, whereas Beta focuses on human cells and the properties of the nanoparticles in order to understand whether they are toxic and, if not, how their properties can be used for medical applications (see Table 4.1).

Table 4.1: Description of the research teams.

	ALPHA	**BETA**	**GAMMA**	**DELTA**	**EPSILON**	**OMEGA**	**TOTAL**
University	University 1	University 2	University 3	University 4	University 4	University 4	
Areas of the activity	Nanotoxicology, pharmacology	Nanobiology, nanotoxicology	Computational physics	Material science	Material science	Material science	
Purpose of the research team	Toxicity and behaviours of nanoparticles within human, mammalian, fish cells and algae	Behaviours and interactions of nanoparticles with biological systems for medical purpose	Properties of nanoparticles through computational simulation for theory and computational tools	Semiconductors growth and nanostructures through characterisation techniques	Chemical interactions on semiconductors surfaces for their electrical properties	Electronic, chemical and structural properties of semiconductor surfaces by using radiation sources	
Type of research	Experimental	Experimental	Both simulation and theoretical work	Experimental	Experimental	Experimental	
Environment	Multidisciplinary	Multidisciplinary	Monodisciplinary	Monodisciplinary	Monodisciplinary	Multidisciplinary	
Founding year	2008	2007	2006	1999	1999	1999	
PhD of the team leaders (year)	- Experimental physics (1989) - Experimental physics (2001)	- Theoretical chemistry (1984) - Chemistry (2002)	Theoretical physics (1999)	Solid state physics (1996)	Surface physics (1983)	Solid state physics (1985)	
Data collection	From May 2009 to September 2011	From March 2011 to December 2011	From May 2011 to December 2011	From July 2011 to August 2011	From July 2011 to December 2011	From August 2011 to December 2011	
Professor	1*	1*	1*		1*		4
Lecturer	1*			1*		1*	3
Postdocs	2	5 (of which 1*)	6		1	1	14
Ph.D. students	6	1	3	3	2	3	18
Individuals	10	7	10	4	4	5	40

* Team leader

4.3.3 Science and technology policies

This section presents the key events in the evolution of N&N in Ireland since the late 1990s. The development of science in Ireland was marked by the launch of the first funding cycle of the Programme for Research in Third-Level Institutions (PRTLI) by the Higher Education Authority in 1998. This round of funding enabled the construction of the centre that hosts Alpha (providing infrastructure and equipment), as well as the two laboratories where Delta, Epsilon and Omega conduct their research. In 2001, awareness of N&N entered Ireland – with the first mention of the word ‘nano’, in ‘nanomaterials’ (Forfás, 2001: 30), in relation to the priority areas of the Sixth European Framework Programme. Forfás is a national agency that analyses policy and advises the Irish Department of Jobs, Enterprise and Innovation.

The country was a latecomer to N&N, but became more proactive about the field in 2003, with the creation of a task force by the Irish Council for Science, Technology and Innovation (ICSTI). The goal of the task force was to evaluate whether the country had the capability to enter the field of N&N, and to identify what potential opportunities in terms of research and the market. ICSTI defined nanotechnology as follows:

> A collective term for a set of tools and techniques that permit the atoms and molecules that comprise all matter to be imaged and manipulated ... These tools and techniques, materials, devices and systems present companies in all sectors of the Irish economy with opportunities to enhance their competitiveness by developing new and improved products and processes (Forfás, 2004: 5). [See Table 4.3 for the full definition.]

A new funding cycle started in 2007; this provided financial resources for Alpha and Beta, enabling them to fund postdoctoral researchers and PhD students as well as to buy equipment. The publication of Ireland’s Nanotechnology Commercialisation Framework 2010–2014 (Forfás, 2010) marked the formalisation of N&N, and identified the areas in which the country should invest (see Table 4.3). The position of Ireland regarding N&N has changed over the last decade, and this can be seen in the evolution of how it is considered.

The definitions of N&N have evolved over the years – from tools and techniques, to a science, before more recently being settled as a general-purpose technology. Having been described by ICSTI as ‘tools and techniques’, nanotechnology became – albeit only briefly, in 2006 – a science: ‘the science of the very small’ (Forfás, 2006: 41). A new direction was taken in 2007, and maintained thereafter, with N&N characterised no longer as a science but as a technology. In 2010, N&N was seen as an enabling technology, in 2011 as a key enabling technology, and by 2012 as a general-purpose technology:

> Nanotechnology is a general purpose technology which involves the purposeful engineering of matter at scales less than 100 nanometers to achieve size dependent properties and functions. Nanotechnology acts as an enabling toolkit which has a broad impact across multiple sectors (Minister for Jobs Enterprise and Innovation, 2012: 36). [See Table 4.2 for the full definition.]

The variation in the definitions shows that, during this rather short period of time, policy makers had difficulties in reaching a consensus on the definition of N&N; this was also the case in other countries that were more advanced in the field.

Table 4.2: Evolution of the definitions of N&N in Ireland from 2004 to 2012.

Year	Definition
2004	‘Nanotechnology is a collective term for a set of tools and techniques that permit the atoms and molecules that comprise all matter to be imaged and manipulated. Using these tools and techniques it is possible to exploit the size-dependent properties of materials structured on the sub-100 nanometer scale 1, which may be assembled and organised to yield nanodevices and nanosystems that possess new or improved properties. These tools and techniques, materials, devices and systems present companies in all sectors of the Irish economy with opportunities to enhance their competitiveness by developing new and improved products and processes’ (Forfás, 2004: 5).
2006	‘Nanotechnology is the science of the very small and is a collective term involving the manipulation of atoms at the scale of a nanometre – one billionth of a metre, or about 80,000 times smaller than the width of a human hair ... Nanotechnology is a generic technology which will lead to new materials and components with new properties. Viewed by some as the next industrial revolution, nanotechnology promises lighter and stronger materials, energy-efficient manufacturing, advances in medical monitoring and bioremediation and much more powerful computers’ (Forfás, 2006).
2007	Nanotechnology ‘is a cross-discipline and cross-sectoral enabling technology that has potentially profound implications across a very wide range of economic activity ... Nanotechnology’s interdisciplinary nature requires cross-discipline cooperation ... The potential implications of nanotechnology go well beyond research, technology, development and innovation, and industry and economic competitiveness. Its development and use will have wider implications in areas such as medicine, healthcare and wider lifestyles, giving rise to associated social, moral, ethical and environmental issues’ (Forfás, 2007: 49).
2010	‘Nanotechnology is an enabling technology that can have a deep and lasting impact on current Irish businesses as well as current and potential FDI [foreign direct investment] in areas such as medical devices and electronics’ (Forfás, 2010: 46).
	‘Purposeful engineering of matter at scales of less than 100 nanometres (nm) to achieve size-dependent properties and functions’ (Forfás, 2010: 19).
2011	‘Nanotechnology is a key enabling technology across multiple markets and sectors ...’ (Forfás, 2011: 51).
2012	‘Nanotechnology is a general purpose technology which involves the purposeful engineering of matter at scales less than 100 nanometers to achieve size dependent properties and functions. Nanotechnology acts as an enabling toolkit which has a broad impact across multiple sectors. The main markets enabled by nanotechnology include the aerospace, automotive, construction, electronics, energy and environment, manufacturing, medical and pharmaceutical and oil and gas markets’ (Minister for Jobs Enterprise and Innovation, 2012: 36).

Table 4.3: Key dates in the development of N&N in Ireland.

Year	Relevant events in N&N policy
2000	- Creation of Science Foundation Ireland as a sub-committee of Forfás: priorities are given to bio and information technologies. - Start of the funding period of the PRTLI cycle 1 (awards made in 1999). This cycle funded the centre that hosts Alpha, as well as the two laboratories where Delta, Epsilon and Omega conduct their research.
2001	- 'Nano' (in 'nanomaterials') is mentioned for the first time in an annual report (Forfás, 2001), as part of the research areas fostered by the Sixth European Framework Programme.
2002	- Start of the Sixth European Framework Programme, with the third priority area being 'Nanotechnology and nanosciences, knowledge-based multifunctional materials and new production processes and devices' (NMP). N&N are funded at the European level in a more structured way.
2003	- A task force is created by ICSTI to (1) establish the nanotechnological capacities already present in the country; (2) identify the opportunities; and (3) create a strategy for the development of nanotechnology.
2004	- ICSTI publishes its report (Forfás, 2004), in which it establishes a roadmap and the different opportunity sectors – such as information and communication technology, healthcare, agriculture and food, polymers and plastics, and construction.
2006	- Creation of a sub-category 'nanotechnology' under 'engineering and technology' within the Higher Education Research and Development expenditure budget. - A technology assessment is made by Forfás in order to identify the investments and policy decisions needed to develop N&N.
2007	- Start of the funding period of the PRTLI cycle 4. This cycle has partly funded Alpha and Beta's laboratories (both equipment and scientists – postdoctoral researchers and PhD students). - Start of the Seventh European Framework Programme. The NMP scheme is maintained. Gamma's research is partly funded by this programme.
2010	- Publication of Ireland's Nanotechnology Commercialisation Framework 2010–2014, which assesses nanotechnology research capabilities in terms of both publications and patents. This study aims to identify the market within which Ireland could be the most successful. It led to the creation of a coordination group in charge of developing nanotechnology industry and assessing the achievement of the previously established goals.
2012	- Considering the downturn in the economy and reduction of budgets, Ireland undertakes a research-prioritisation exercise in order to avoid financial-resource dispersion. Nanotechnology is considered as an underpinning technology rather than a prioritised area of research.

4.3.4 Data collection

The data collection comprised two stages. First, one author interviewed each team leader in order to collect information about the research specialty (Chubin, 1976) and its purpose, team members, how and why the team was created, how the team obtained its funding, how it sustains its activities, the journals targeted and conference attended, and to what funding agencies it submits applications. This round of interviews provided the authors with an initial description of the activity and its environment. The first stage was completed using internal documents, such as funding applications and presentations. Not all research teams were able to provide this type of documentation, due to issues of confidentiality with their collaborators. Information gathered in the interview with the team leader was triangulated through interviews, during the second stage, with the postdoctoral researchers or PhD students. Websites were also a good source of information, often being used to advertise team activities and promote the chosen image.

The second stage consisted of interviewing stakeholders related to the activity of interest to our study: team members, policy makers and funding agencies. Their identification was not predetermined, being led by the first stage of data collection. This was essential in order to obtain a thorough description of the team, the various aspects of its activities, and the different stakeholders that are directly or indirectly involved. Postdoctoral researchers and PhD students were interviewed to develop a better description of the activity and to avoid giving too much weight to the data collected from the team leaders (Miles & Huberman, 1994). Initially, team members were interviewed about their career paths (both their backgrounds and why they chose to come to the laboratory), their sense of N&N, and their view of the political and funding environment. Curricula vitae (CVs) were used in order to objectivise their paths and to collect more thorough information on why they moved into N&N, as well as their sense of this field. As journals enable new knowledge to be diffused and to reach scientists who could then become involved in the process, they are essential to the emergence of a new science (Frickel & Gross, 2005). CVs were therefore also used to gather information about the journals in which the interviewees publish. We also collected data about the conferences that team members attend. Conferences play an important role in the process of emergence, as they are a venue where diverse participants can exchange information and visions of the future that can lead to the constitution of a field (Garud, 2008; Lampel & Meyer, 2008), in addition to being a context for mobilisation (Frickel & Gross, 2005).

Then, data about the STP environment and funding agencies were collected in order to build an understanding both of the actions undertaken to develop the field of N&N area and of the context in which these took place. More than 2000 pages of documents were studied to generate a detailed description of how STPs have evolved since the late 1990s, and how N&N has emerged in this context. Data were completed and rounded out with interviews of individuals in charge of the N&N scheme in the relevant agencies. This part of the data collection started with interviews at Forfás – of a science and technology representative, and a representative of N&N – in order to construct a global framework in which N&N policy could be conducted and constructed. In order to complete the information about the actions undertaken to foster N&N, the chair of a group – Ireland Nanotechnology Coordination Group – that aims to coordinate N&N actions throughout the country was also interviewed. The dataset was further enriched by documents and interviews with individuals from the agencies cited by the team leaders and members: Forfás, Science Foundation Ireland; Enterprise Ireland; the Environmental Protection Agency (EPA); the Irish Research Council for Science, Engineering and Technology (IRCSET); and the Seventh European Framework Programme. For this set of interviews, questions were related to the evolution of N&N in interviewees' areas, how the agencies promote these lines of research, the policy directions their agencies are willing to take, their own sense of N&N, and the ways they want to fund it (see Table 4.4).

Data collection in the second stage was rounded out with a second interview of the team leaders in order to gain clarification on the dataset, obtain more information about the team, and ask follow-up questions. We enquired about what the agencies provide money for (infrastructure, equipment and scholarships); how this impacts their research (number of students, publications, research area, etc.); and, in a context of budget reduction and shift from recurrent to project-based funding (Laudel, 2006a), what their strategy is to sustain their activities. This dataset provides a process description of how the events from both political and scientific contexts have unfolded over time. Studying the conditions of emergence through process data (Langley, 1999) is appropriate as it involves both new and existing actors and, moreover, both the creation of new resources and the recombination of existing ones.

Table 4.4: Description of the political actors.

	Forfás	**Science Foundation Ireland**	**Enterprise Ireland**	**EPA**	**IRCSET**	**Seventh European Framework Programme**
Description	Advice to the Department of Jobs, Enterprise and Innovation. This agency provides research and advice in the areas of enterprise and science to the government.	Main agency to fund basic research within three main areas: biotechnology, information and communication technology, and sustainable energy and energy-efficient technologies.	Agency responsible for the development of Irish companies. It funds applied research and projects that have a possible industrial applications.	Agency that funds projects directly related to protecting the environment. Its role is also to provide rules for pollution-causing activities and to monitor the environment.	Its role is to support research at the master's, doctoral and postdoctoral levels. Funding is provided based on the relevance of the project and the student who will carry it out.	Framework Programmes are one the main European funding instruments. Among the different schemes, funding was provided for projects in the N&N area.
Data	Documents and interviews (3)	Documents and interview (1)	Documents and interviews (2*)	Documents	Documents	Document and interviews (2*)

* These delegates to N&N are also the contact point the Seventh European Framework Programme and therefore they have interviewed in quality of both roles.

4.3.5 Data analysis

We based our study on a qualitative and inductive approach (Strauss & Corbin, 2007), and followed three main steps in the analysis. First, we wrote tick descriptions in order to describe the logics promoted by the policy makers and by scientists. We detailed both the evolution of N&N policy since the late 1990s (describing the actions undertaken by the government) and that of the research teams (describing their creation and activities, and how they have been sustained over time). Second, we focused on identifying how the processes have unfolded over time, identifying how political actions have impacted the research teams as either opportunities or as threats, and how the research has been affected by these external changes. Finally, we focused on answering the research question. We provide more detail on each of these three stages below.

4.3.5.1 First step: Writing tick descriptions

As Ireland has invested massively in science since the late 1990s, we included information related both to the global context of science and technology policy and to the development of N&N. This was built on raw data, such as documents and interviews related to STPs (investments in science, evaluation and assessment of the research capacity, Forfás annual reports from 1998 to 2010, and national developments) and to N&N (changing definitions, its evolution, the same annual reports, N&N-related investments, funding agencies' paperwork). Using process data (Langley, 1999) enabled us to understand how the events unfolded over time. One of the main STP investments was the PRTLI (launched in 1998, with the first funding period being 2000–2003), which funded the infrastructure within which some of the research teams are hosted (Alpha, Delta, Epsilon and Omega). These programmes have also funded equipment, as well as postdoctoral researchers and in some cases PhD students (Alpha and Beta). The content of the annual reports has been essential to understanding the wider social context in which the teams are evolving.

Regarding the evolution of N&N in Ireland, we focused on when the word ‘nano’ (both nano* as in ‘nanoscience’ and ‘nanotechnology’, and *nano* as in ‘bionanotechnology’) appeared for the first time within the annual reports and what triggered this. The definitions were also an important indicator, as their meanings show the logics within which this area is fostered. Even though the events have occurred over quite a short period of time (roughly 12 years), the definition has evolved from a tool, to a science, to an enabling technology. We then paid attention to the evolution of the budget and restructuration of the categories, with the creation of the ‘nanotechnology category’.

Then, for each case, we built a description that detailed the boundary decisions and creation related to the activity, and the political and scientific environment. Each research team was described in terms of the different projects that constitute the team as a whole, the backgrounds of the members, and how the team is funded. We also described the funds gathered to build the infrastructure, funds used to sustain the activity (building or renewing the infrastructure, equipment, hiring postdoctoral researchers and PhD students, etc.), and the strategy to develop and sustain the activity in the future. Once we had produced this global framework, we described the backgrounds of all team members, their projects, to what extent N&N is included in their research, the scientists with whom they collaborate, the journals targeted and conferences attended, and the directions in which they want to take their careers. These different themes allowed the authors to gain a sense of how the team members perceive their environment and N&N, what their scientific community is, and how they see themselves evolving within this community; in other words, how they delineate and draw the boundaries of N&N.

4.3.5.2 Second step: Identifying the logics and focusing on the boundary evolution

The evolution of the boundaries of the logics was dealt with separately for policy makers and scientists, in order to distinguish their different visions. Indeed, because of their divergent interests, the two communities involved in this phase of emergence might perceive the emergent area differently. Moreover, given their idiosyncrasies – background of the members, parent disciplines, techniques, journals targeted and so on – laboratories were first analysed independently (Eisenhardt, 1989, 1991; Miles & Huberman, 1994; Yin, 2009). This allowed new themes to emerge. We focused on five themes in particular: (1) how the activity emerged and for what purpose; (2) the opportunities (political, funding-related, and scientific) that enabled the team to be created; (3) the extent to which N&N is part of their work and their own identity; (4) the conditions for building a scientific community (outcomes in terms of journal and conference publications); and (5) the meanings attached to the field of N&N. These five themes were applied to all levels – team leader, postdoctoral researchers and PhD students – in order to avoid elite bias (Miles & Huberman, 1994).

Themes (1) and (2) were used to identify the physical boundaries of the logic promoted by policy makers. These boundaries were identified through the laboratories in which scientists were conducting their research, whether the word ‘nano’ was clearly displayed in the names of the laboratories, and whether they used equipment such as atomic force microscopes or scanning tunnelling microscopes (often employed in research at the nanoscale). For instance, for Alpha, the expertise of the team leader in spectroscopy techniques enabled him to investigate the new area of toxicity of nanoparticles to human cells. As the government supported this stream of research, Alpha has been able to obtain funding to buy equipment, and to hire postdoctoral researchers and PhD students.

Themes (3) and (4) were important in describing the social boundaries of the new logic, through the discipline and the scientific community with which scientists identify and interact. We particularly looked at whether scientists integrate N&N into their identity through the use of first-person pronouns ('I', 'we', etc.), marking a detachment from established disciplines. For instance, for Alpha's scientists, who are involved in a new area of interactions of nanoparticles with biological systems, N&N is deeply integrated into their identity and the meaning they share about their activity: 'Nano and nanotechnology and everything is very different from the other kind of strands of science because pure development is chemistry, pure toxicology is biological' (Alpha 3.1, PhD student). For Delta, Epsilon and Omega's scientists, working at the nanoscale is more inherent to the discipline of materials science and does not represent a new area of science: 'I generally don't try to sell my work as nanotechnology … People hear nanotechnology, they hear all sorts of wonderful things that might happen in the future' (Delta 3.2, PhD student).

As N&N encompasses multiple disciplines (Heinze et al., 2007), we were able to identify through theme (4) whether the different research teams have some journals in common, or whether there are main events in N&N at which scientists can meet, no matter their backgrounds and disciplinary embeddedness.

Finally, mental boundaries were identified through themes (4) and (5). A common event (such as a conference) was expected for the structuration of an emerging field (Garud, 2008), since scientists tend to go to conferences related to their own projects rather than more multidisciplinary, generalist events. Theme (4) is related to the meaning and identity that go beyond the organisation and span the scientific community (Hernes, 2004a). Theme (5) – relating to how scientists expect N&N to evolve – was a focus in order to reveal how the research teams (mainly team leaders) position themselves within an emerging area where relationships between the actors have been modified (Maguire et al., 2004) and where having a clear position enhances visibility. For instance, Gamma is part of a research centre dedicated to N&N, which gives the team national and international visibility.

4.3.5.3 Third step: Answering the research question

During the last stage, we focused on answering the research question: to what extent can powerful actors, such as funding agencies, trigger institutional change by influencing the reconfiguration of the boundaries of science? By using a composite-boundary perspective (Hernes, 2003, 2004a, 2004b), we described how each type of boundary – physical, social and mental – evolved for each case under the influence of the same political environment. We qualitatively show the evolution of N&N within the political sphere, and the different consequences of these decisions for different teams. Including multiple teams in our study allows both similarities and dissimilarities to emerge and, therefore, provides a more detailed understanding of the extent to which a powerful actor impacts an area along its physical, social and mental boundaries.

4.4 FINDINGS

4.4.1 Partial transformation of laboratories and of practices

National and supra-national funding in N&N has changed the scientific landscape of science in Ireland over the last decade. Indeed, laboratories have been built in order to undertake research in the different domains of N&N, such as materials, medicines and drug delivery. Various funding schemes are used to provide scientists with financial resources. They can be differentiated by their intrinsic goals, as some were created to fund N&N in particular, while others are broader but include N&N in their scope. Funding schemes such as PRTLI cycle 4, Science Foundation Ireland, EPA, and IRCSET not only focus on basic N&N research but also fund applications in this area. The government has encouraged N&N by fostering agencies to fund N&N applications. Even though Science Foundation Ireland is the main funding agency created to fund basic research, its objectives were modified as application-oriented research became a higher priority. The Integrated Nanoscience Platform for Ireland (INSPIRE) is a consortium of 10 universities (eight from the Republic of Ireland and two from Northern Ireland) which has as its main purpose the funding of N&N in three areas: nanoelectronics, nanophotonics and bionanoscience. This consortium was the main funder of Alpha, and enabled Beta to buy equipment and to fund scholarships (see Table 4.5).

Table 4.5: Funding agencies and research teams.

Type of funding	Alpha	Beta	Gamma	Delta	Epsilon	Omega
INSPIRE	Equipment and scientists	Equipment and scientists				
PRTLI cycle 4	Infrastructure and equipment			Equipment	Equipment	Equipment
Science Foundation Ireland		Infrastructure, equipment and scientists	Infrastructure and scientists	Scientists	Scientists	Scientists
European Union		Scientists	Scientists			
EPA	Scientists	Scientists				
IRCSET			Scientists	Scientist	Scientist	Scientist

Ireland's political decisions – manifested through its funding schemes – have increased the country's international visibility as it is now one of the main countries producing publications in N&N. We observed different degrees of transformation. First was the creation of new organisations. This deep organisational change was characterised by creating a new laboratory *ex nihilo*, recombining existing resources or joining a research centre dedicated to N&N. European and national funding was used by scientists to delineate a new organisation that better fitted the new environment and the rise of N&N, and that was more visible to both policy makers and the scientific community. Within these new physical boundaries, scientists from multiple backgrounds, enabled by these techniques and this equipment, were able to explore new areas, such as nanotoxicology and nanomedicine:

> I really felt it was a bandwagon until I really started to think, I don't know even in the past five years, 10 years, it's only then that I really felt that, hang on, there is something else which is more than just a bandwagon, more than just a way of getting of grants, more than just a buzzword in the area of nano. I only felt that recently. (Alpha 1.1, team leader)

This was particularly the case for Alpha and Beta which, respectively, recombined extant resources and created a laboratory *ex nihilo*. In 2007, a new funding cycle started, which has been very beneficial to Alpha and Beta (respectively created in 2008 and 2007) as it supported a consortium dedicated to N&N of which these two teams are members (see Table 4.5). This consortium fosters the development of N&N related to materials and biological systems by funding equipment, postdoctoral researchers and PhD students. Beta targeted both European and national sources of funding, and began the construction of a new laboratory; European funds were used for personnel, while national funding was used for infrastructure and equipment. It was built upon common projects between Beta's leader and a postdoctoral researcher (Beta 2.1). These projects enabled them to obtain a grant that would fund the construction of a new infrastructure.

Between acquiring the grant and opening the building, the team was hosted by the department of molecular biology at the university to which it is attached. Alpha, meanwhile, mobilised national sources of funding and founded the laboratories on pre-existing capabilities. So, although the infrastructure was already present, the consortium enabled Alpha to buy N&N-related equipment and to fund postdoctoral researchers and PhD students. Of the two groups from which Alpha was built, one disappeared and the other was renamed. The aim of this change was to gather together the scientists conducting research at the nanoscale, who were previously scattered in different groups, in order to make them more visible. The goal of the laboratory was to group scientists around core spectroscopy techniques. Scientists came from two main branches: the characterisation of nanoparticles, and the toxicity of nanoparticles. Although these two branches were meant to be distinct in the original proposal, both postdoctoral researchers and PhD students ended up extending their research to cover both areas.

As an example of the second degree of transformation, Gamma did not really create new physical boundaries but joined the biggest research centre in Ireland dedicated to nanomaterials and nanodevices. Gamma’s research activity is therefore categorised under the sub-discipline of computational physics. Using super-computers, they simulate how one or two atoms behave under certain constraints. As dealing with atoms and their properties is the purpose of their discipline, their work is deeply embedded in theoretical physics and computing – but mainly in N&N. Moreover, the evolution of computational science is more linked to improvements in computers and their capacity to deal with information than to technological advances in microscopy and lithography. So, though not being tied by the experimental side of science and the cost of instruments, Gamma can adapt its research and find applications for its work in more favourable and fashionable areas, if this improves the team’s sustainability.

We turn now to the third degree of transformation. Although funding was available and laboratories had the capabilities to apply for this, some did not engage in adopting N&N in their physical boundaries. Moreover, even though their equipment is used for research at the nanoscale, they did not try to renew it in order to improve their facilities. This non-adoption is illustrated by three cases: Delta, Epsilon and Omega. Their practices did not change as they are embedded in the continuity of previous ones.

In the first three cases (Alpha, Beta and Gamma), laboratories adopted the N&N logic within the physical boundaries of their organisation. The change in logic was made in different ways – from creation to joining an extant infrastructure. By adopting the N&N logic, these laboratories made themselves visible to both the political and the scientific communities. Moreover, the material aspect of the new logic (at least for Alpha and Beta) deeply modified the practices of the scientists, as they were led to work with the same pieces of equipment and on similar interdisciplinary projects. Under the same political pressures, other laboratories did not bend their trajectories, despite having the capabilities to do so. In that case, policy makers – even though they were powerful actors – did not convince all potential scientists to move to an interdisciplinary and application-oriented area (see Table 4.6).

4.4.2 Core, peripheral, and rejection of N&N into social boundaries

Identity is a complex phenomenon, but it is interesting to examine, as professional identity is enacted within – but also spans – an organisation's boundaries. As identity is constructed in interaction, how it interplays with members of other organisations and the scientific community is important in understanding the emergence of social boundaries that bear the N&N logic. We found that the symbolic elements of the new logic were either centrally or peripherally integrated, or not integrated, within the social boundaries. These three types of boundary, although distinct elements, interact with and mutually influence each other (Hernes, 2004a). First, the laboratories that created new physical boundaries adopting the N&N logic triggered the emergence of a new identity with central N&N elements. These physical boundaries enabled scientists with multiple backgrounds to create in their interactions a new identity that differed from established disciplines and existing departments. This identity is even stronger for young scientists who started their scientific careers by doing a PhD in this new area. For both Alpha and Beta, N&N and multidisciplinarity are strong characteristics of the teams' identities. For instance, as Alpha was created from the reshaping of two groups, historical linkages and interactions already existed before the new group was created. However, even though these two groups work on biological systems, the emergence of social boundaries enabled scientists to locate themselves within the centre. We observed similar results for Beta, as it was created before the infrastructure. While the infrastructure was built, Beta was hosted in another department in order to start to conduct experiments. Even though this was a centre dedicated to biology, the creation of Beta with a name and a purpose of its own enabled the group's members to distinguish themselves from the centre staff:

> I don't know how to define it in the sense of, like, this department is the Department of Molecular Biology. For example, we are doing something strange with respect to them. (Beta 2.3, postdoctoral researcher)

In both organisations, members (especially those who started their studies in this new area) constructed an identity that would define them and separate them from scientists in other disciplines. In these cases, the construction of sense and identity has been enabled by the creation of a new entity delineated by physical boundaries: a name, a purpose and an infrastructure with equipment, where scientists can conduct their research.

For the laboratories for which multidisciplinarity is less important, or less relevant to their research, the construction of an identity that would fit N&N was much less salient. We observed that a new identity was not created but that N&N was included in the existing identity. This is in line with previous work on identity that shows that '*identity is tailored to fit the work at hand, and not vice versa*' (Pratt, Rockmann, & Kaufmann, 2006: 242). Delta and Gamma highlight this result; there, N&N is a peripheral rather than core feature of their identity. Delta's team leader emphasises the incremental aspect of N&N in his research. As the team is working on sensors, N&N is a way to produce better sensors or to grow better materials; N&N is not an end in itself. In this way, the lack of established standards makes N&N more of a trend and a buzzword than a technology that deeply impacts their discipline. Moreover, in a similar vein to Gamma, Delta locates its research in the discipline of materials science. So, this embeddedness in an established discipline, the lack of established standards in N&N, and the multidisciplinarity that characterises this area have together made it difficult for Delta to take account of N&N in its identity. However, even though Delta's leader never felt the need either to create a new entity or to rename his team to include 'nano', they are working at the nanoscale, and they therefore use techniques related to this area:

> I still consider myself to be working on semiconductor physics and nano-structured semi conducting materials. So I would see myself as having a strong nano aspect to my work.
> (Delta 1.1, team leader)

In a similar vein, Gamma's social boundaries include and adjust the N&N element, depending on how it fits the research area. Theoretical physics and computational physics can be adapted to fit a specific application-oriented area. In that sense, the team can adapt its research – for instance to solar energy, to fit a call for funding from Saudi Arabia. For these two teams, N&N is not seen as the main characteristic of their identities, but as a peripheral feature that helps to distinguish them from others and to adapt their activities to environmental changes.

For Omega and Epsilon, N&N is considered a trend, a fancy term, although they work at the nanoscale. Surprisingly, one of Omega's members (Omega 3.1) considers his team and Epsilon as being the 'nano department', even though no department or any other entity has a name that contains the word 'nano'. This can be explained by the fact that he is a PhD student who had recently started his PhD at the time of the interview, and that 'nano' was in the description of his project. Epsilon's members – and especially Epsilon's team leader – have a more drastic view of N&N, perceiving it as a trend that does not define the area in which they research. They consider themselves as doing basic science. For them, N&N would be the building of material from molecules, whereas they are studying the basic aspect of materials science. This vision is shared by the postdoctoral researcher and PhD students, who see themselves as working in an area that is very relevant but has no direct applications to the industry:

> I don't care if people do not think I am a nanotechnologist, because the area we work in of thin film and interfaces is of critical importance in so many areas. Particularly the area that I work in, which is the semiconductor and how devices work are dictated by the interactions between surfaces. And essentially the layers we look at are of the nanometre dimension and range. (Epsilon 1.1, team leader)

Their identity is forged around the techniques and the molecules they are using, and N&N is not even a characteristic they use to differentiate themselves from other teams or disciplines (see Table 4.6).

4.4.3 A partial nanoscience and nanotechnology research but a paradigm-based science

In our study, conferences and journals are another important aspect of science, as they enable scientists to present their work, share ideas and build collaborations, and they can be a locus for emergence (Garud, 2008; Lampel & Meyer, 2008). As places where norms, practices, beliefs, etc. are shared, discussed and challenged, they are an important regulatory mechanism (DiMaggio & Powell, 1983; Ruef & Scott, 1998). We found that only a few conferences, and even fewer journals, are fully dedicated to N&N. So, for a team that adopted N&N into its physical and social boundaries, and thus distinguished itself from established disciplines, it was more difficult to find the same distinction in the scientific community. The same research project sometimes had to be split into pieces in order to fit the requirements of different journals, for example by emphasising the physics- or biology-related aspects of the study.

For Alpha and Beta, with activities spanning multiple established disciplines, conferences that encompass the full range of their work are difficult to find. Even though N&N related to biological systems is core to the teams and common to all members, each project shows some specificity that would make attendance at broad conferences not very useful. For Alpha, the technique or the type of cells that scientists are working on – in other words, the core of their research – drives the conferences they attend. The learning aspect of conferences is very important for PhD students, as they meet experts in their techniques. Multidisciplinarity makes it difficult to possess the expertise within the boundaries of the organisation. For Alpha, for instance, team members attend conferences according to their work:

> [Alpha 3.5]'s work is being presented at SETAC [Society of Environmental Toxicology and Chemistry], you know, and I would like [Alpha 3.4]'s work presented at SETAC too which is an environmental conference, okay. So, obviously this aspect of toxicology and her project would go into that. So you just yeah ... Generally, anything nano-bio you'll go to. But if there's some aspect of the project that was specific, you know, go to them. [Alpha 3.1], anything food-related obviously, he is going to go to. [Alpha 3.2], if it's something to do with confocal microscopy, generally speaking, you know, it's a good thing for you to go to that because, you know, that would be more for her technique. She could see what other people are doing, stains they are using and, you know, possibility of using another cell observer, you know. (Alpha 2.1, postdoctoral researcher)

It follows that the dual aspect between N&N and the inheritance of techniques from established disciplines make the emergence of a common ground difficult. Although multidisciplinary conferences, where diverse actors meet to deal with the application- or regulation-related aspects of N&N, are useful, they would not address the scientific side of their work. As N&N does not have its own standards, scientists must learn from knowledge existing in established disciplines. For instance, Beta's members tend to attend both conferences that deal with the N&N aspect of their work and those that deal with the core scientific knowledge underpinning their work:

> I was going for the more chemical conferences like physical chemistry, like about synthesis of nanomaterials and applications or the stuff like that and then I decided that I had to ... When I started working with the cells, I decided that I have to go for the conferences that will be something about cells. So we went for the conference about endocytosis. (Beta 3.1, PhD student)

The very broad spectrum of N&N makes the emergence of common social events rather difficult, since the specificity of each research project is tied to a type of knowledge embedded in an established discipline. As scientific impact is harder to achieve at very broad-based conferences, given that peers will not necessarily be present, embracing N&N also constitutes a way of making an impact on an existing discipline. This is relevant, if we consider the scientific heritage within which organisations such as Alpha and Beta are embedded, and the novelty value brought by their focus on N&N. Even if both these teams have members who attend broad-based N&N conferences, they also try to impact existing communities in order to establish their scientific relevance. For instance, physics techniques might be very useful in molecular biology as they can provide biologists with better images of the cells, and so deepen their knowledge of living organisms. For Alpha and Beta, although they integrated N&N into their physical and social boundaries, the diffusion of a new type of knowledge is rather difficult as it does not fit the current institutionalised structure of science. Indeed, although there are nano-dedicated journals, their articles were published both within and outside the WOS category of N&N (see Appendix F, p.224, for an illustration). One the one hand, this highlights that both Alpha and Beta use quite intensively the word nano in their publications and one the other hand, that categorisation of nanotechnology according to the WOS is only partial. Indeed, even though this can also questions the institutionalisation of nanotechnology, it illustrates that research at the nanoscale, for these teams, do not fit the extant structure of science.

For Gamma and Delta, broad N&N conferences – although interesting in terms of finding out what is happening in the N&N field in terms of applications – are not relevant enough to help them make progress on the scientific side of their work. Both of these teams are evolving in sub-disciplines of science that have been encompassed by N&N, but that find their roots in established communities. Indeed, even though computational science is a rather newer discipline than materials science, both were born before the take-off of N&N in the late 1990s. Conferences organised around N&N are usually too broad to be beneficial to their work, making collaborations difficult to establish. In both cases – and in a similar way to Alpha and Gamma – scientists from Gamma and Delta attend conferences that are deeply related to their work:

> When I go to a conference, I would like it to be sufficiently specific that I can really, really learn a lot about the things I am interested in. These very broad conferences with medical applications and social science and health and safety, I don't deny they are interesting, I don't mean to say they are not interesting, but I don't know that I would find them as useful. (Delta 2.1, postdoctoral researcher)

In both these cases, the monodisciplinarity and embeddedness of their research in an established discipline mean that N&N conferences are too general to be relevant. Even though generalist conferences structure their communities, these events are traditionally materials science events, such as the American Physical Society's March Meeting, or European Materials Research Society. Exchanges with their respective scientific communities are made by going to workshops or small conferences in order to meet their peers and establish collaborations. In a similar vein, as N&N is a peripheral characteristic of their identity, scientists can go to conference with sub-themes dedicated to N&N. The latter is seen more as a specialisation than as a brand new discipline.

As mentioned earlier, Gamma joined a research centre dedicated to nanomaterials and nanodevices, but Delta did not engage in creating or renaming an organisation. However, although they both make sense of N&N as a multidisciplinary trend that encompasses their discipline, Delta increasingly uses the word 'nano' in its publications. So, both teams adjust to environmental pressures in different and partial ways. Gamma has modified the physical boundaries of its organisation, whereas Delta has modified how it engages with the scientific community. For both teams, the use of the word *nano* was mainly in their respective communities (see Appendix F, p.224, for an illustration). Although they started to use the word nano quite recently compare to their academic career, there were no inflections to the trajectories of their research.

This completes the social boundaries and nanotechnology more as a peripheral characteristic of their identity rather than a core one.

In a similar way to their approach to targeting publications, the broad conferences that Omega and Epsilon attend are dedicated not to N&N but to surface science. We have seen that neither Epsilon nor Omega engaged in creating a new entity or in renaming their organisations. Although this is similar to Delta, Epsilon and Omega see N&N as a buzzword and a trend, even perceiving themselves as being outside this vision. As a consequence, they barely use the word *nano* in their publications (see Appendix F, p.224, for an illustration). These teams were rather reticent to use the word nano in their publication which is in line with the integration of nanotechnology in their identity. In that sense, at all levels of boundary, they do not engage in this area of N&N (see Table 4.6).

Table 4.6: Logics and types of boundary across cases.

	Alpha	**Beta**	**Gamma**	**Delta**	**Epsilon**	**Omega**
Physical boundary	N&N logic	N&N logic	N&N logic	Paradigm-based science logic	Paradigm-based science logic	Paradigm-based science logic
Social boundary	N&N logic (core)	N&N logic (core)	N&N logic (peripheral)	N&N logic (peripheral)	Paradigm-based science logic	Paradigm-based science logic
Mental boundary	N&N logic	N&N logic	Paradigm-based science logic	Paradigm-based science logic	Paradigm-based science logic	Paradigm-based science logic

4.5 DISCUSSION

We used a composite-boundary framework (Hernes, 2004a, 2004b) within the institutional-logics perspective (Thornton et al., 2012; Thornton & Ocasio, 2008) to describe the impact of powerful actors on the reconstruction of science boundaries to allow a new area of science to emerge. We saw that, although STPs enabled some changes among incumbent organisations, the adoption of the application-oriented and multidisciplinary logic has been only partial. By applying this framework, we showed that funding agencies initially impact the physical boundaries of organisations, while social and mental boundaries are still tied to a certain extent to the scientific communities. This shed light on dynamics that would otherwise have remained hidden (Beckert, 2010). Our study makes four contributions.

First, even though internal actors had the right capabilities, scientists did not necessarily move to the new, financially attractive area; this finding is in line with other studies based on the same fieldwork (see Granqvist et al., 2012). This calls for discussion in order to improve our understanding of institutional change and shift in logics. While most studies have described logics as both material and symbolic (Lounsbury, 2007; Rao, Monin, & Durand, 2003; Thornton, 2002), and rightly emphasise that both elements are necessary for the rise of a new logic, we see here that it is essential to undertake more detailed analysis in order to deepen the dynamics during an institutional change. The interplay between the three types of boundary shows that forcing organisations to adopt a new logic through funding will mostly push them to adopt the physical structures but not necessarily the symbolic elements (Friedland & Alford, 1991; Thornton et al., 2012; Thornton & Ocasio, 2008) necessary for a new logic to emerge. Indeed, the mental ties are essential for a community to function (Porac et al., 1989, 2011, 1995), and are not directly constrained by the physical structure, as the latter can be decoupled from the activity (Fiss & Zajac, 2006). This point is supported by Granqvist and Laurila's (2011) study, which shows that the ideas promoted by the futurist, science-fiction community permeated the scientific sphere and enabled scientists to reframe their own concepts. Moreover, in the primary phase of institutional change, when multiple actors are involved and are competing to promote their own logic, it is useful to identify on what element both the new and the old logics crystallise. In our case, while organisations' physical boundaries were partially ruled by the new logic, social and mental boundaries were still guided by a paradigm-based-science logic. This leads to a misalignment between the three types of boundary, which can trigger tensions. Indeed, boundaries are not independent from each other, as the delineation of a physical boundary eases the construction of a new and common identity for individuals from different backgrounds. Moreover, mental elements provide a framework within which to construct the social and regulative element (Ruef & Scott, 1998). Because the policy makers' intervention failed to reconstruct the mental boundaries of scientists, the way that scientists considered N&N was hindered by their discipline, and a necessary consensus for a discipline could not be reached. Beyond this partial institutionalisation, this implies a better understanding of the co-existence of institutional logics.

Reay and Hinings (2009) show that competing logics can coexist through the development of collaborative relationships, and that the competition between logics is not necessarily solved by one becoming dominant (Hoffman, 1999). Moreover, multiple logics can influence the practices and identities of both individuals and organisations (Battilana & Dorado, 2010; Goodrick & Reay, 2011). Describing multiple logics might help us to understand how a new logic succeeds in becoming dominant, or fails to do so. This is relevant for professional fields that face an institutional-logic shift (Lounsbury, 2007; Reay & Hinings, 2005; Thornton et al., 2005), and for hybrid organisations (Battilana & Dorado, 2010; Pache & Santos, 2012). Even though logics are constituted of both material and symbolic elements (Friedland & Alford, 1991; Thornton et al., 2012), it is important to describe which of these elements are primarily impacted by the challenging logic. Indeed, as fields are constituted of multiple and sometimes conflicting elements (Beckert, 2010), they are unlikely to be deinstitutionalised all at once. Professional norms are enduring, and are sustained through the presence of professional associations (Marquis & Lounsbury, 2007). In scientific fields, even though application-oriented and multidisciplinary research is spreading and becoming dominant, the disappearance of the paradigm-based logic is contested. Indeed, the two logics have always been there, but the rise of the new is explained more by a shift in dominance between the two logics rather than by the rise of a new logic. This is in line with Reay and Hinings (2005), who argue that '*when a dominant institutional logic exists, it is because other logics are subordinate*' (p. 352). So, even though an institutional change can be witnessed at the field level, it might not be the case at the micro level (Stål, 2011).

Our second contribution lies in the call for further discussion of the notion of decoupling during logic shift. Decoupling occurs when organisations structurally conform to the environment but their activities remain unchanged (Meyer & Rowan, 1977). In that sense, and related to our study, an institutional change can be witnessed at the field level by observing the transformation of incumbent organisations and newcomers – while at the micro level, it might occur more slowly, or even not happen. Surface compliance happens when the physical boundaries conform to institutional pressures (Fiss, 2007). In our study, under the influence of powerful actors, physical boundaries seem to be more fluid than social and mental boundaries – or at least to change faster than the two other types of boundary. While institutional theorists focus on either change or stability, we argue that both must be considered in the study of logic shift – under the notion of institutional inertia, which Hoffman (1999) describes as a consequence of the institutional process. Following the concept of decoupling, institutional inertia must be applied to all three types of boundary in order to better grasp where change occurs and from which it comes. In this study, change has been witnessed at the physical level, and to a lesser extent at the social and mental levels of the organisations. By applying the composite-boundary framework to logic shift, we complete previous works that show that multiple logics can coexist, in particular not disappearing but remaining crystallised on the social and mental boundaries of organisations.

Third, we make an institutional contribution to STS studies by highlighting the ‘structuring structure’ of the extant scientific disciplines. Even though a new logic is transforming the infrastructures of science, where research takes place, the cognitive structure within which paradigms are embedded remains very stable. While the physical structure of organisations changes, knowledge production is still controlled by invisible colleges (Crane, 1972; Price & Beaver, 1966). This stability plays an essential role in the production and diffusion of outcomes. Indeed, these structured ways of thinking are inscribed during the different degrees and deepened during research, with the organisation of journals by disciplines. To follow Latour (1998), science is cold and detached, whereas research is warm and involving. Although researchers from different disciplines are gathered within the same space, moving from one epistemic arena to another (Knorr Cetina, 1982, 1999), these arenas remain very stable and not easily disrupted. This study goes further than previous work on scientific-discipline emergence (Frickel & Gross, 2005), as most earlier studies argue that change comes from within science, and therefore first impacts the social and mental boundaries of the discipline. So, if nanotechnology did not trigger a Kuhnian revolution, with the destruction and disappearance of the old paradigm, what has changed? A Popperian revolution might be more appropriate. Indeed, the birth of new research avenues – such as in medicine – can lead us to a new paradigm, with new ways of approaching biological systems at the nanoscale. However, neither physics nor molecular biology has been disrupted by nanotechnology. The cognitive pillar is ruled by invisible colleges that are stronger than visible ones. So, the application of a composite-boundary framework calls for deepening our understanding of where the loci of science lie, and how the structuration of emerging disciplines occurs.

Finally, we contribute to research and policy by showing that the invisible college of science organises the profession; this makes it a more difficult lever for change than modifying the infrastructures. If we use the analogy of the Triple Helix (Leydesdorff & Etzkowitz, 1996, 1998b), the cognitive structure of science would be the bases that link the strands together. So, even though new organisations emerge, this does not drastically modify those that already exist, changing them only marginally. In that sense, institutional logics prevail over organisations. However, this does not mean that policy makers, through their funding schemes, do not impact scientific disciplines. Indeed, the stability of an institutional logic is maintained over time by the equilibrium between its material and symbolic elements – and, as detailed in this study, between the physical, social and mental boundaries. By changing the physical boundaries of a logic, policy makers break this equilibrium and trigger new dynamics within science. Extant disciplines engage in boundary adjustment by relabeling their discipline to conform to nanotechnology, expanding their authority over this emerging area, or emphasising the boundary between their activity and nanotechnology (Grodal, 2010). Moreover, new areas of research have emerged, such as bionanoscience, thanks to the drawing of new physical boundaries. So, despite being unable to change the deep cognitive structure of science, policy makers can steer science by introducing new dynamics into extant disciplines.

4.6 CONCLUSION

This addressed the first sub-research question: To what extent can powerful actors, such as funding agencies, trigger institutional change by influencing the reconfiguration of the boundaries of science? It provides element to understand the influence of policy makers on the emergence of a new scientific discipline. By using a composite-boundary framework, we show that the boundaries of an organisation can be modified along three dimensions. Policy makers can modify the physical boundaries of organisations; this may look like institutional change at the field level. However, the social and mental structures of organisations remain ruled by the old logic. Therefore, the boundaries of organisations can be modified at different levels. Moreover, by breaking the equilibrium between the three types of boundary, powerful actors can introduce new dynamics to an established field.

Chapter 5.

Convergence and multidisciplinarity in nanotechnology: Laboratories as technological hubs[†]

5.1 INTRODUCTION

> At conferences it can be quite difficult when you are dealing with people who are purely in one area because you need to have knowledge of every area, you need to be able to discuss those areas with different people. So you do need to know a lot and you need to be very comfortable with the things that you know. So it is difficult. The nano field is quite difficult like that because we don't have a particular home like other scientists. (Comment from an interviewee, PhD student)

Nanotechnology is considered as an emerging and converging technology (Roco & Bainbridge, 2002; Roco, 2008) that is said to be one of the key technologies of the 21st century. Through an expansion of the label 'nanotechnology' (Grodal, 2007, 2010), multiple and diverse organisations and communities are gathered under this umbrella term. Nanotechnology is a young domain and encompasses disciplines such as applied physics, materials science, physical chemistry, physics of condensed matter, biochemistry and molecular biology, and polymer science and engineering. These diverse sciences collaborate together in order to understand the specific properties of the nanoparticles and to contribute to the scientific knowledge and, to make new medical

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devices, more resistant materials and more efficient transistors (Bhat, 2005) among an unlimited number of other possibilities that are likely to change a number of industries (Avenel et al., 2007). However, this scientific multidisciplinarity remains understudied.

Whereas scientific boundaries have been studied in the sociology of science (Gieryn, 1983, 1999) little attention has been given in management science to the convergence of multiple scientific disciplines around a technology and its organisational consequences. Indeed, scientometric studies suggest that nanotechnology is a set of overlapping scientific disciplines (Meyer, 2001, 2007) mainly driven by physics and chemistry (Bassecoulard et al., 2007; Schummer, 2004b). However, the understanding of what happens within this overlap is still under-explained.

Following the problem-solving logic, specialisation tends to be the characteristic of modern sciences (Popper, 1970). Scientific disciplines are embedded in paradigms that condition the way of thinking, legitimise the practices and rule the scientific activity (Kuhn, 1970). Usually, when a new discipline emerges within a new paradigm, we witness the creation of degrees that are entirely dedicated to the new discipline, PhD programmes that hold the name of the new discipline, new applications, etc. However, nanotechnology seems to counter this scheme by integrating multiple scientific disciplines around the same technology. In this way, crossing scientific boundaries means to face other methods, practices, ways of thinking, and so on and, thus, to constrain the production of scientific outcomes. From these observations, I ask the following research question: How do scientists involved in a scientific area crossing multiple scientific disciplines use multidisciplinary knowledge in order to create a new scientific outcome?

To answer this research question, the study has been organised as follows. First, a point is made on what we can learn from the philosophy and the sociology of science and the categories that can be constructed from these disciplines in order to understand the sciences born after the Second World War (Bonaccorsi, 2008) such as nanotechnology. Second, from this framework and through a qualitative and exploratory study, I argue that laboratories are technological hubs through which scientists converge from multiple scientific backgrounds. As such, they have to be understood through the physical, social and cognitive boundaries that delineate them. Although they are working in the same laboratory and sometimes on the same project, scientists face cognitive barriers that constrain the collaboration between scientific disciplines. Finally, from the results, different issues are raised in order to question the evolution of the field of nanotechnology and the future research that can be undertaken in order to highlight the specificity of the area of nanotechnology.

5.2 BOUNDARIES AND MULTIDISCIPLINARITY IN SCIENCE

5.2.1 An insight from philosophy and sociology of science

According to Popper, science has to be falsifiable and must be falsified (1959). In other words, scientists must try to prove that their hypotheses are wrong instead of right in order to improve the research programme (or paradigm in the sense of Kuhn; both will be used in the same sense in this study). If a theory is tested and proved right through the process of falsification it has to be accepted and, conversely if it is proved wrong it has to be abandoned. Lakatos (1970) argued that core hypotheses are protected by a shield of auxiliary hypotheses which will be abandoned, improved or created. In this way, old research programmes are not necessarily destroyed by new ones. For instance, when Einstein discovered the theory of relativity, Newton’s theory was not abandoned. It is still being used and improved. In opposition to Kuhn, Popper and Lakatos showed that a new science can start without disrupting another. Moreover, modern sciences tend to follow a theoretical problem-solving approach and to be more and more specialised (Popper, 1970). Kuhn (1970) argued that scientific disciplines are embedded in paradigms that condition the way of thinking, legitimise the practices and rule the scientific activity. He defined paradigms as a set of fundamental concepts and hypotheses, practices, methods and beliefs. Scientists do their everyday life activities oriented and guided by these rules without sometimes being able to define them precisely (Kuhn, 1970). Within these guidelines, scientists are in charge of testing all different hypotheses, improving the theory and providing the scientific community with a wider understanding of the world. That is what Kuhn named ‘normal science’. The latter defines the boundaries of the scientific community within which practices are accepted by the community, scientific problems solved (Kuhn, 1970) and knowledge accumulated and shared (Merton, 1973).

Sociology of science also gives sense to scientific boundaries. Boundary construction is a prerequisite for ‘inner’ scientists if they want the discipline to grow, to evolve and to become an established science which will be independent from states, industries and other scientific disciplines (Gieryn, 1983). First, boundaries are essential for scientists to pursue professional goals such as intellectual authority and career opportunities (Gieryn, 1983). Indeed, expert knowledge can only be claimed by a limited community of scientists. If accepted by every scientist, knowledge becomes tacit and is integrated into instruments (Latour, 1987). Second it is among an identified community that scientists can gain credit and climb up through the grades of the scientific hierarchy (Latour & Woolgar, 1979). Third, drawing boundaries enables the identification of fundamental knowledge, methods, ways of thinking, etc. that will be supported by institutions and taught in class in order to reproduce and to maintain the scientific community.

Within these boundaries, data is produced and artefacts transformed into facts in order to be published, accepted and thus objectivised to finally become the new reality of a specific scientific community. (Latour, 1987) argues that to understand the whole process, human and non-human actors have to be studied together. Indeed, the construction of scientific facts cannot be understood without taking into account the human actors who interpret the results, build arguments and write articles and those who use this article and thus participate to the diffusion of a new idea. Then, instruments are considered as ‘black boxes’ whereof results produced are legitimate given the instrument is acknowledged by the scientific community and is no longer a controversial issue. Instruments are not mere machines that transform through their processes the reality into charts, figures and graphics but also produce data which once accepted by the scientific community will be the scientific reality. The latter is built by scientists that use other scientists’ arguments in order to build theirs. When the argument is accepted, it is transformed into tacit knowledge and incorporated into instruments which will bring this tacit knowledge into another scientific discipline.

To sum up, following the problem solving logic, specialisation tends to be the characteristic of modern science (Popper, 1970). Scientific disciplines are embedded in paradigms that condition the way of thinking, practices and rule the scientific activity (Kuhn, 1970).

5.2.2 Multi- and interdisciplinarity in science

Science has undergone significant changes in the past few decades. As described by the triple helix model (Leydesdorff & Etzkowitz, 1998a; Leydesdorff & Meyer, 2007; Leydesdorff, 2000), boundaries between science, government and industry have been blurred. The view of homogeneous and closed scientific communities is challenged by recent works on a shift between two ways of doing science (Bonaccorsi, 2008; Bonaccorsi & Thoma, 2007; Gibbons et al., 1994; Nowotny et al., 2003). Described by Gibbons et al. (1994) as 'mode 1', old sciences, such as physics, chemistry, biology and their sub-disciplines, are characterised by disciplinary, university-based and government-based laboratories. 'Mode 2' describes sciences that are characterised by being multidisciplinary, based on networks of knowledge and oriented towards problem solving and societal challenges. Bonaccorsi (2008: 296) argues that new sciences are 'reductionist sciences that address new complex phenomena by breaking the boundary between natural and artificial'. They are measured through three different indicators. First, the rate of growth shows a constant entry of new fields that grow very quickly after entry and a high turnover rate. This contrasts with 'old' science whereof changes were paradigmatic and revolutionary, and normal science (Kuhn, 1970) characterised by a slow rate of growth. Second, the degree of diversity brings to light the difference between diversity before and after paradigmatic change and diversity within normal science and also questions the number of directions that can be pursued at the same time. This indicator shows that new sciences generate new hypotheses within established paradigms with weak or strong divergence. This is very different to old sciences, where divergence was exceptional. Third, the level and type of complementarity show the process of cross-disciplinary competence building, new forms of infrastructural utilisation design or institutional cooperation. This last indicator is based on the structure of affiliation and institutional complementarities in publications. This shows that industrial affiliations as well as that of the number of occurrences with multiple research institutions and with companies is much higher in new sciences than old sciences.

These views of new sciences highlight the involvement of multiple scientific disciplines around the same object which is characterised either as multidisciplinary or interdisciplinary. First, multidisciplinarity involves at least two disciplines (Heinze & Bauer, 2007) and is described as ‘a rather loose, additive or preliminary relation between the disciplines involved’ (Schummer, 2004b): 11). In a multidisciplinary context, although different disciplines overlap which fosters wider knowledge, information and methods, scientific disciplines remain separate from each other and the structure of knowledge is not questioned (Klein, 2010). Multidisciplinarity thus is a primary step towards interdisciplinarity that requires ‘strong ties, overlap, or integration’ (Schummer, 2004b): 11). So when interactions between at least two scientific disciplines become more proactive, the new area can be described as interdisciplinary.

5.2.3 Motivations and research question

The use of the 1–100 nm scale to define nanoscience and nanotechnology (N&N) do not explain whether different established scientific disciplines are converging and what is happening when scientists with different backgrounds are collaborating. For instance, working with molecules is the purpose of chemistry (Grodal, 2007). Moreover, the convergence between scientific disciplines is not completely new and is still controversial. Material science, one of the disciplines crossed by nanotechnology, is the result of a convergence between physics and chemistry.

Different and disparate technological and scientific fields are converging towards N&N. This convergence is said to ‘fuse’ the traditional disciplines (Islam & Miyazaki, 2010) in order to lead to a new area of research (Linstone, 2011). However, the reason of this convergence is still discussed. One the one hand, Loveridge et al. (2008) argue that the artefacts made at the nanoscale (nano-artefacts) are the basis of this convergence. One of the attributes of these nano-artefacts is to integrate multiple scientific and engineering disciplines; the other attributes being the 1–100 nm scale and a pervasive characteristic. On the other hand, Schmidt (2008) sees the convergence of different disciplines as a shared use of instruments such as atomic force microscopes or scanning tunnelling microscopes. So, in his view, it is less the particle or the device in itself that characterises the convergence than the different ways to produce them. Moreover, the view of a complete convergence towards a unified area of research has not yet reached consensus among the scholars.

Scientometric studies bring useful insights regarding the different controversies that nurture the discussion about the new area of N&N. Schummer (2009) argues that there is no strong evidences for claiming a scientific revolution based on new tools. Indeed, scientometric studies, through citation and co-citation analysis, tend to show that the area of N&N is more characterised by an aggregation of disconnected disciplines than a multidisciplinary convergence. N&N does not reveal any particular patterns of interdisciplinarity and must be considered more as multiple mono-disciplinary scientific fields sharing the prefix ‘nano’ than a new unified area of research (Schummer, 2004a). So, although the word ‘nano’ has spread, boundaries of science have not really been challenged by this new technology.

Although on the one hand, there is a call for more interdisciplinary collaborations in N&N by policy makers and on the other hand, scientometric studies balance the interdisciplinary characteristic of N&N, we do not know what happens in a laboratory where scientists with different backgrounds collaborate. The motivation of the study is twofold. First, although some studies have been done on the different types of scientific outcomes that a mono- or a multidisciplinary team can produce (Porac et al., 2004), little is understood about how a scientist uses knowledge from multiple disciplines in order to create a new outcome. Second, funding dedicated to N&N has been increasing over time (Roco, 2005). Even if N&N is not well understood as yet – unrelated disciplines or a new single scientific discipline – nanotechnology has the potential to enhance nations' productivity (Roco & Bainbridge, 2002) and thus bring a serious competitive advantage to organisations that use, either in the process or in the product, technologies at the nanoscale. Dynamics that occur in these very specific organisations have to be better understood if they want to be fostered and developed. While multidisciplinary teams tend to produce more varied concepts than mono-disciplinary ones (Porac et al., 2004), the determinants of the knowledge creation need to be better understood to enhance the comprehension of these knowledge-based organisations.

This study has been designed to deepen the knowledge on how scientists with different backgrounds produce scientific outcomes in a multidisciplinary context and how they experience this multidisciplinarity. Even though science and even scientific disciplines are difficult to be precisely defined, the theories mentioned earlier help to frame the different foci that are important to look at in this specific context. We first saw that scientific disciplines are embedded in paradigms (Kuhn, 1970) in order to enable knowledge accumulation (Merton, 1973: 268). This is materialised by the different schools that teach students specific concepts, methods, way of thinking, etc. and that agree with the paradigms within which the disciplines are embedded; in Schummer's words, 'a social context of transmission and education and a social body that thereby reproduces itself' (2004b: 11). However, these boundaries are not easy to transcend. Indeed, path-dependency research suggests that emotional reactions such as uncertainty avoidance, cognitive biases (selective perception, implicit theories) can lead to a lock-in situation (Sydow et al., 2009). Rafols & Meyer (2007) give another view of interdisciplinarity in N&N by arguing that cross-disciplinarity does exist in terms of ‘cognitive practices’, i.e. use of references and instruments, but much less in terms of affiliations and backgrounds of the researchers. In this way, scientists cite articles from other disciplines but regarding their collaboration, they tend to stay in their original discipline. I here refer to Weick (2003) to define practices as ‘equated with doing, concreteness, understanding, know-how and wholes’ (p. 454). So, within this framework, I focus on how multidisciplinary or interdisciplinary research is practiced and ask the following research question: How do scientists evolving in a scientific area crossing multiple scientific disciplines use multidisciplinary knowledge in order to create a new scientific outcome?

The next part describes the methodology that has been followed and then findings will be presented and discussed.

5.3 METHODOLOGY

5.3.1 Case study research design

This study meets the three criteria set up by Yin (2009) for which a case study design is suited. First, I focus here on a ‘how’ research question which aims at describing how scientists practise multidisciplinary research. Second and third, this study focuses on a contemporary event for which the behaviours cannot be manipulated. N&N is a young domain (Heinze et al., 2007) whereof the attributes such as multidisciplinarity is not fully understood yet. Next, the study took place in a laboratory—which will be described below—where scientists do their research on a daily basis.

This case has been chosen for its endogenous attributes (Siggelkow, 2007). Indeed, the research group on which the study is based focuses its research on particles at the nanoscale and encompasses scientists with multiple scientific backgrounds. Studying a research group as a whole instead of experiments has been chosen because it allows consideration of ‘the full spectrum of activities involved in the production of knowledge’ (Knorr-Cetina, 1992: 115). I will first describe the research centre and then the research group which has been studied.

The research centre was founded upon the basis of multidisciplinarity with the common denominator of optical characterisation and spectroscopy. The research centre has been built thanks to a national grant in 1999. The objectives of this funding programme were to develop research capabilities, to give support to individual researchers and research teams and to foster the cooperation between and within institutions. In this way, the objectives of the proposal were based on extending the capabilities of the existing research groups but with the possibility to build new ones, on the construction of shared facilities and on the objective to develop interdisciplinarity at both the research and education levels. At the beginning, six research groups were defined and were clustered around the core laboratories. These research groups focused on radiation and environmental science, environmental chemistry, inorganic chemistry, physics of molecular materials, holographic research and solid state physics. In 2004, two main changes occurred. Firstly, two other groups were hosted in the building (one focusing on wireless communications and the other on engineering surface coating). The second change was the evolution and redefinition of the physics of molecular materials and solid state physics groups into two new groups: nanophysics and the solar energy group. The increasing worldwide development of N&N led the research centre to develop further knowledge in this area of expertise.

The drive to develop N&N research resulted in the research centre introducing several activities at the nanoscale scattered in different groups. Building on internal competencies (biology and physical characterisation), managers of the research centre decided to focus on biological aspects of nanotechnology. In order to do this, the nanophysics group disappeared and, in 2008, a new group focusing on nanotoxicology and nanobio-interactions was created: Alpha (pseudonym). This group gathered together the different PhD students and postdoctoral researchers that were doing research at the nanoscale under the discipline of nanobio-interactions and specifically nanotoxicology.

Nanotoxicology is an emerging sub-branch of toxicology which aims to study the impact of nanoparticles on human health and the environment (Oberdörster et al., 2005). Nanoparticles have the particularity to be able to traverse the cell membranes (Seaton & Donaldson, 2005) and thus lead to unexpected consequences. If non-toxic, these particles present properties that can be used in domains such as drug delivery or cancer therapy (De Jong & Borm, 2008). Scientists within Alpha not only study human cells but also extend their study over the whole food chain by analysing algae, fish, and mammalian cells, particularly human. Although this discipline is a sub-discipline of toxicology which is mainly a biological discipline, the first step of an experiment is to characterise the nanoparticle (defining size, shape, surface area, etc.) which involves physics and chemistry. Then, biology-related experiments are undertaken to test the nanoparticles in order to determine their characteristics and their toxic effects on different types of organisms and cells.

The laboratory is mainly divided into two spaces: physical and biological experiments. The first space, dedicated to physical experiments, includes instruments used to characterise size, shape and surface area of the nanoparticles. The second space, dedicated to biological experiments, includes separate rooms that are dedicated to the study of fish cells, mammalian cells or human cells. Both spaces can be used by all scientists in the conduct of their research. PhD students and postdoctoral researchers have very different backgrounds, such as physics, chemistry, biology and toxicology. Although the collaboration is limited between them, projects are multi-disciplinary, including physics – mainly physical characterisation – and biology. However, as the process is complex and the project is characterised as multidisciplinary, the steps between the different disciplines are identifiable.

5.3.2 Data collection

This study relies on two sources of data. The first source of data is archival documents. It includes a book that traces the history of the research centre from 1999 to 2006 and of the different grant proposals, reviews and presentations that are related to the development of Alpha. This helped to have a better understanding of the history of the research centre in which the research group is embedded, as well as how this new research group is developed and justified. The second and main source of data is based on 12 semi-structured and 11 structured interviews (see Table 5.1). The respondents were defined by their membership to Alpha. This research group is made of the manager of the research centre, one lecturer, two postdoctoral researchers and six PhD students. The manager of the radiation and environmental science group has been included into the study as she is deeply involved in all biology-related experiments. Three steps have been followed.

Table 5.1: Description of the interviewees.

Position	Number of interviews	Post graduate diploma	PhD discipline	Topic
Research centre manager	3	physics	physics	laser physics
Lecturer	3	physics and chemistry	physics	carbon60 and fullerenes
Research group manager	1	physics and chemistry	biology	radiation biology
Postdoctoral researcher and laboratory manager	2	physics	physics	carbon nanotubes
Postdoctoral researcher	2	biology	molecular biology	iron oxide nanoparticles
PhD student	2	analytical chemistry	nanoscience	mammalian cell toxicology
PhD student	2	applied chemistry	nanoscience	mammalian cell toxicology
PhD student	2	toxicology	nanoscience	ecotoxicology
PhD student	2	biochemistry	nanoscience	mammalian toxicology
PhD student	2	toxicology	nanoscience	ecotoxicology
PhD student	2	toxicology	nanoscience	drug delivery

The first step includes semi-structured interviews with the manager of the research centre and the lecturer. Questions were related to both the research centre and the Alpha in order to have a global understanding of the reasons why they decided to develop N&N within the centre and more particularly nanotoxicology. These interviews were conducted in order to fill the gaps and to add precision to the information gathered with the archival documents. The second step consists of the first round of interviews that were conducted with the manager of research centre, the lecturer, the two postdoctoral researchers and the six PhD students. During this round of interviews, respondents were asked to talk about their research. To do so, they were asked to describe what tasks they are doing on a daily basis such as the type of journals they are reading, the different types of experiments they have done and need to do so for their research and their interactions with the other members of Alpha. Interviews were open-ended in order to let new themes emerge. This first round of interviews allowed the identification of global themes that were used to frame the second round of interviews. These themes were the vision they have of Alpha and the integration of different scientific disciplines. The open-ended nature of the interviews allowed the emergence of the tensions that might occur on the one hand when they have to make an experiment which is outside their scientific background and on the other hand, when they collaborate with scientists that have a different scientific background from theirs.

The third stage of interviews includes structured interviews that were conducted with the manager of the research centre, the research group manager, the lecturer, the two postdoctoral researchers and the six PhD students. This approach was undertaken in order to compare the different themes between the interviews. These structured interviews were divided into three main parts. First, they were asked to describe their path from their undergraduate studies until their current position. Second, they were asked to describe Alpha and to explain what makes it different from another scientific laboratory dedicated to N&N. Third, they were asked to describe their work by relating each step to a specific discipline. This has been done in order to understand to what extent their work is multidisciplinary. Then, they were asked the types of journals they are reading and citing, and the ones they are targeting. These questions were coupled with the conferences they are going to. Finally, they were asked to describe a collaborative experience (a simple experiment or a whole study). For each set of questions, an emphasis was given to the tensions they might have experienced.

The interviews were recorded and taped except one during the first round but for which notes were taken and transcribed the same day. The interviews lasted from 45 to 100 min. All data was anonymised. When an interviewee referred to another laboratory and the quotes included in this study, names were replaced by Alpha, Beta and Gamma.

5.3.3 Data analysis

Miles & Huberman (1994) advise that data collection and data analysis have to be intertwined from the start. Overlapping these two stages enables to fasten the analysis and to reveal adjustments to the collection of data (Eisenhardt, 1989). Although three steps were detailed in the data collection they were part of the data analysis and the emergence of the themes. The three steps define the adjustments in the data collection and the deepening of the understanding of these three steps. To do so, an inductive approach has been used and for which I travelled back and forth between the data collection and the theoretical understanding (Glaser & Strauss, 1967). The three steps of data collection reflect the back and forth process between data and emerging theories as well as the focus on more and more narrowed categories. I integrated the coding schemes that were related to multidisciplinarity and scientific knowledge production. The coding scheme enabled me to keep focus on the research question that I sought to address: how do scientists evolving in a scientific area crossing multiple scientific disciplines use multidisciplinary knowledge in order to create a new scientific outcome? To answer the research question, I developed a list of first order codes and worked on this list in order to obtain non-repetitive statements. These open codes are made up of the words that the respondents used. These first order codes were then revised in order to generate aggregates that encompass the first order codes. They were finally gathered under key themes that structure the findings that are developed below: democratisation of the equipment, development of a specialisation in N&N and finally, perception of the area of N&N.

5.4 FINDINGS: SCIENTIFIC LABORATORIES AS TECHNOLOGICAL HUBS

5.4.1 Democratisation of the equipment

Contrary to biotechnology, nanotechnology requires expensive equipment in order to be able to see, to manipulate and to control molecules at the nanoscale. This equipment has enabled all scientific disciplines to see at the nanoscale and thus to validate or to invalidate theories. However, in the 1980s and early 1990s, this type of equipment was very expensive and only reserved for big laboratories. So, even if the theory allowed scientists to have an understanding of the nanoscale, small laboratories were not able to conduct experiments. Then, Gerd Binnig and Heinrich Rohrer from IBM-Zurich in Switzerland won the Nobel Prize in 1986 for the invention of the scanning tunnelling microscope. After its commercialisation, small laboratories were also able to conduct experiments at the nanoscale. With the scanning tunnelling microscope (STM) and the atomic force microscope (AFM), two essential tools in nanotechnology, scientists are able to see and to manipulate single atoms. The democratisation of these two materials led laboratories to be equipped with tools enabling research at the nanoscale.

The atomic force microscope and the scanning tunnelling microscope have changed scientific disciplines, not by modifying their way of doing science or the internal scientific logic, but by bringing new possibilities that were just theoretical. So, physicists who traditionally had a top-down approach reached the level of the atom and thus were able to better understand the physical properties as well as to manipulate and thus to make materials. Although the term was not used, experiments at the nanoscale were already possible with this equipment. So, more than real breakthroughs, possibilities offered by this microscopy were a natural step in the scientific evolution.

> In physical science, in physics and chemistry, it’s more or less a continuum but the real huge step, the real revolution of understanding was in 1910, 1920. I suppose from that came the AFM, the electron microscope, the atomic force microscope. From that came the ability to review everything. I think it was a huge step and since then everything has been increasing. And then, you have things like the AFM. That provides then some support for bio, for genetics. Suddenly being able to see and being able to manipulate, that kind of enables all the other disciplines. There was a huge step in the science, technology of course improved but there was nothing really that enables genetics. I would think that’s the key enabler. It’s not just AFM, STM, it’s generally scanning probe. This enables to see and manipulate at the nanoscale. (Manager of the research centre)

These instruments have challenged the scientific disciplines by enabling them either to confirm or to refute their theories. This technological breakthrough has challenged at the same time multiple disciplines by giving the scientists the possibility to ‘push’ their disciplines to the nanoscale. So, multiple scientific disciplines that had a theoretical understanding of the atom such as quantum physics could from now on conduct experiments at this scale. So, new scientific avenues of collaboration are possible. However, this technology has not disrupted all scientific paradigms and completely changed their interactions. Although equipment has enabled scientific disciplines to see, to manipulate and to control at the nanoscale, this has not made them melt into one single scientific discipline.

5.4.2 Development of a specialisation in N&N

Alpha developed its specialisation in line with the groups and competencies that were previously available in the research centre. Indeed, they based the speciality of the research group on the radiation biology group and, the nanophysics group that was dissolved. Based on this internal stock of knowledge – characterisation of particles at the nanoscale and biological understanding of cell death – they developed the specialisation of the research group in the area of nanotoxicology. The development of a domain of expertise is linked with the need of being visible and to have cutting edge facilities. All three are linked together. Indeed, to perform research at the nanoscale, specific equipment such as atomic force microscopes, scanning electron microscopes, etc. is necessary. Although this type of equipment is available on the market and thus available to all laboratories, they remain expensive. So, laboratories have to resort to external funding in order to buy nano-related equipment.

As highlighted in the grant proposals, justifying the need for funding relies on the relevance of the work for science and society. In the case of Alpha, the relevance for the scientific community is described as a need for a better understanding of the properties of the nanoparticles and how they behave in cells. This lack of understanding is also relevant for society as nanoparticles can potentially be harmful. In this way, risks have to be assessed. The project is justified by internal capabilities such as the scientists that are carrying on the project and their areas of expertise as well as previous publications in these scientific domains. Being visible in the area enhances the chance of the proposal being accepted. Publications justify the competencies of the scientists as being accepted by the scientific community and thus providing the latter with new and accepted knowledge (see Table 5.2).

Table 5.2: Development of a specialisation in N&N – Open codes and aggregates.

Quotes	Open coding	Aggregates
‘I think this is a niche to be able to approach from the two angles, like the physics, physic-chemical kind of characterisation and then the toxicology’.	Being specialised into one area	**Expertise**
‘Alpha I don’t think is doing any toxicological study and Beta they are more into like applications. Beta has started looking a bit at the toxicological part but always it was more the application thing. Gamma was parallel to us, to the application and the toxicological part. If I put the Nanolab in that perspective Gamma are well established, so as Beta and we are evolving’.	Positioning the lab with potential competitors	
‘They had the facilities for cell culture that I needed as well as the spectrometry and the expertise of that part. It was a good opportunities for me that is why I took it. That was my main reasons for coming to Alpha’	Seeking an expertise in a specific area	
‘It’s good to have Alpha recognised as a centre because it means it’s recognised as something unique and important and having unique skills and equipment’.	Benefiting from the recognition	**Visibility**
‘The nano thing is more highlighted. Definitely it is some sort of recognition. And the recognition is always needed is this field because there are specific nano lab research centres.	Looking for recognition	
‘We are collaborating with Gamma and because we have the facilities to do the eco part they don’t’.	Having specific equipment	**Facilities**
‘That’s why the funding was set up for my lab. [..] That specifically bought the DLS, bought the ultra-low temperature freezer that’s what the cells are in, bought the incubator, pretty much bought everything in the lab’.	Need for funding	
‘We don’t need more instruments. Whatever instruments we have, they’re already the best’.	Working with cutting edge instruments	

Although the domain of expertise is influenced by public funding, the development of a speciality in the case of Alpha is also based on an internal stock of knowledge and competences.

5.4.3 Scientific boundaries: between heritage and adaptation

Scientific backgrounds are embedded in established scientific disciplines that provide scientists with guidance in their way of doing research (Kuhn, 1970) on the one hand, and enable scientists to identify and to locate themselves in a multidisciplinary environment on the other. Although Alpha hosted scientists from PhD students to professors that are every day in a multidisciplinary environment, they still perceived the boundaries that are inherent in their respective scientific education. This scientific heritage bounds the scientist into a way of thinking and methods. This is within this monodisciplinary embedment that a research can be part of the cumulative process of scientific knowledge production (Merton, 1973). In the case of Alpha, this scientific heritage can be identified when scientists with different backgrounds are collaborating on the same project. The different biases led by the theoretical foundations of a discipline, methods, vocabulary and so on, create boundaries that can hinder the creation of knowledge.

> That was the funniest thing. She wanted to work with ppm, particle per million. And this milligram, what the hell is a milligram, what you’re talking. She thought we were insane. And she said how much the cell can actually receive. We couldn’t tell her because all the other things that are going to happen in the process, and they all won’t be the same size. The idea for us, we can blindly, well we don’t blindly accept but we understood why our sample wouldn’t be uniform. (Postdoctoral researcher and manager of the laboratory)

In a multidisciplinary project and collaboration, scientists have to locally adapt themselves in order to produce a new outcome. In the case of Alpha and more generally in the discipline of nanotoxicology, scientists have to first characterise the nanoparticles before testing its toxicity. This first step is essential as they can afterwards relate the properties of the particle to its toxic effect. In this way, the ‘multidisciplinary label’ is used by scientists when they integrate physical characterisation to a biological study. Depending on the instrument which is used to understand the properties of particles, the level of involvement in other scientific discipline can vary.

> It depends on the techniques you’re using to characterise. If you’re using something like a DLS, it’s quite an automatic system. You prepare a solution quite easily, just by diluting nanoparticles and then you put into the machine and press go whereas if you’re doing something like AFM or TEM or STM, there’s a quite lot more of involvement in it. (Postdoctoral researcher)

Collaborating on a multidisciplinary project leads scientists to create local practices and adaptation. Methods are borrowed from established protocols in order to be validated and justified in another. However, in order to introduce physical knowledge in a biological paper, explanations cannot be reduced to the main references but have to be extended.

> Two reviewers said fine publish as it is and one reviewer basically wanted a greater explanation of the absorption-desorption. So we had to put the statement in the paper. From time of review, probably four and a half months from the start of the experiment and to get it published. That was very quick but that was a very solid experiment, very simple but it showed a very strong effect. That was the only bad thing, the bad review. We presume, this person was a biologist and he didn’t understand the experiments. (Postdoctoral researcher and manager of the laboratory)

When the level of involvement is high, it is compensated with extensive readings and, most of the time, by a return to the basics of the discipline. Although the development of knowledge from other disciplines eases the communication between scientists and thus improves multidisciplinary research, it also hinders the process of knowledge creation by limiting the accumulation process.

> When I read papers and when I go to conferences and I see people working with the same cells as me and the same particles as me, they just seem to be always two steps ahead, even miles ahead. (PhD student, background in applied chemistry)

Troubles in performing multidisciplinary research have mainly been expressed by PhD students. The lack of global vision of the area of N&N and knowledge in a particular discipline raises two types of constraints. The first constraint is related to the supervision of the PhD. As they are supervised by scientists coming from one established discipline, PhD students that are doing their research in the area of N&N, and here in nanotoxicology, cannot benefit from knowledge in all disciplines. The supervisor will be competent in one area but the PhD student will have to train her/himself in the other discipline. The other constraint is related to the publication of the research. Although multiple journals have extended their scope to N&N, only a few are generalist. In this way, multidisciplinary studies cannot be published as a whole and as a full process of reflection. Even though they are justified by a problem-solving approach, they have to be split in order to fit an established discipline (see Table 5.3).

> When you’re writing a thesis, it’s much easier to write a thesis if you have a lot of publications, you know which I don’t have unfortunately because of those difficulties. And there are other people that complain about the same. So, I don’t think it’s just me. (PhD student, background in analytical chemistry).

Table 5.3: Scientific boundaries: Between heritage and adaptation – Open codes and aggregates.

Quotes	open coding	aggregates
‘I come from a very much physical background and physics tends to question thing, why is that happening. Probably I want to take the thing apart, and mix up the filter and arrange and stuff. They’re just happy with that and just leave it there. Whereas we want to understand what it is doing it, the fundamental concept is behind, how you’re taking the measure’.	Experiencing different ways of thinking	**Scientific heritage**
‘I’m an analytical chemist, when I’m talking about the concentration of something I refer to it as ppm which is part per million. A pure chemist would use mole or molarity or the number of mole’.	Having knowledge depending on a single scientific discipline	
‘I think that a chemist would probably more understand the molecular biology than I ever will’.	Being limited to cross disciplinary boundaries	
‘I characterise the nanoparticles here, the nanoparticles that I’m using, their chemical structure, the characterisations, the size measurement, the Omega potential measurement’.	Using instruments as multidisciplinary knowledge	**Adaptation**
‘It is generally agreed that they are certain measurement that should be made for material. But, that’s just our own group. Worldwide or Europe, there is no protocols. I can’t look up a protocol for nanomaterials. Each group is starting to come across their own way of measurement. We have our own ways, and they’re other research group that they their own certain ways. So at the moment it is becoming knowledge of the different ways’.	Creating local practices	
‘I have no real experience with biology before I started my postgrad. But my postgrad is a little dependent on biology. So I have a lot work to do in that area because particularly from my perspective. Because I am concerned about how toxic nanomaterials are. I need to really understand how biological systems react to something. I just took a lot of learning when I started my postgrad. I just had to do a lot of study just to get up to the speed on biology’.	Filling knowledge gap in order to integrate multidisciplinary knowledge	
‘I have trouble publishing papers. I’ve written a paper that has shown that such and such material is toxic when it comes out of this material here. [...] Now, when I send that to a journal, the journal will say, it’s not really a toxicology paper it’s a material science paper. And I send it to a materials journal and they will say there is too much toxicology. It’s not a materials journal paper, you know. So, I find it difficult to publish some studies. One of the ways that I can go above that is the split the study down into small chunks’.	Having troubles to produce a scientific outcome accepted by the community	**Constraint**
‘My supervisors are great, I’m not saying that they’re not great but I do feel as I said some of the other guys who the toxicology or even the biology experience. All of my supervisors are physicists by trade’.	Working an area that does not benefit from cumulative knowledge	

5.4.4 Perception of the area of N&N

The perception of these boundaries will, however, differ in function of the background of the scientists and the definition that is attached to the label nanotechnology. As mentioned earlier, nanotechnology is at the crossroads of many disciplines. The definition of nanotechnology from 1 to 100 nm is not enough to include or exclude scientists with different backgrounds into one homogeneous scientific community. Indeed, some works and thus knowledge are included in the area of nanotechnology without explicitly being named or labelled as such. So, depending on what the scientist considers as part of the area of nanotechnology, his perception of his own scientific boundary and those of nanotechnology will differ. Moreover, although nanotechnology is said to cross a multitude of scientific disciplines, a distinction is made between science and technology in order to separate the knowledge production and the application of this knowledge. So, multiple boundaries are perceived between science and the applications.

> Nanoscience would evoke very much the scientific content. That wouldn't necessarily include engineering. [...] There is other stuff out there which is nanotechnology and has always been nanotechnology, we've just never labelled it nanotechnology. So a lot of paint, emulsion paint and so on will actually be on the nanoscale but we've never redefined that. Manufacturers in atomic force microscope are dealing with very much large components but they're building tools for nanoscience. That would fall into the category of nanotechnology. (Lecturer)

The lack of clear definition and the difficulties regarding both the research and its publication lead young scientists to see themselves as either pioneers of a new and promising area of research or as not belonging to an established field. First, by seeing N&N as a new area of research, they describe their practices as different from established disciplines such as physics, chemistry or biology. Integrating physical experiments into biological studies is the first step to new ways of doing research.

Moreover, by being in a multidisciplinary environment and going to conferences dedicated to N&N or more especially to nanotoxicology, they tend to develop a proper identity and distance themselves from established disciplines.

> Nanoscience is in its child step, very basic science, no one knows properly if it can help or if it can be harmful. At some point when many more people will work on this, then definitely, different works will come together and give us a story. (PhD student, background in toxicology)

On the other hand, these practices that are not embedded in an established discipline and the non-alignment between the scientific disciplines, the practises and schools tend to create confusion when young scientists try to describe their discipline, what they are doing, and who they are.

> I would be a biologist, with a degree in chemistry, registered with school of physics. (PhD student, background in applied chemistry)

These types of confusion are present among PhD students but not among senior researchers. Their research is linked with their previous and established background. Their perception of the area of N&N is related to their research and how they can relate it N&N. They would tend to emphasise the enabling characteristics and the instruments rather than the scientific aspects (see Table 5.4).

> I'm materials. Actually, do I define myself by: I'm laser physicist because originally I was working with laser in laser physics? Am I material? If I'm material, I'm chemical physicist, am I physical chemist? I am not physical chemist, I'm physical chemist. And certainly now, I am not nanoscientist. Maybe I'm too old to be a nanoscientist. (Manager of the research centre)

Table 5.4: Perception of the area of N&N – Open codes and aggregates

Quotes	Open coding	Aggregates
'Nanotechnology simply is a way of describing the evolution of material and research in life the sciences enable by the ability to see and manipulate material at the nanoscale; just simply, moving on the research to a different dimension'.	Describing N&N as technological evolution	**No standard definition of N&N**
'Suppose you have been working all your life at hundred and twenty nanometres. You miss everything, you can't call yourself a nanoscientist, you can't apply for all these funding, you can't publish in all these journals because you're at hundred twenty nanometres. That's a joke, nobody really draws a line'.	Discussing the standard	
'The main focus in toxicology is nano-particles because is such a new area and they just grow more and more. [...] I mean when I was in college there was no talk about nanoscience, nanoparticles, nanotechnology. It just wasn't happening. But now, it's just become so new, there is so much research now'.	Seeing N&N as growing and promising area of research	**Pioneer**
'I think nano and nanotechnology and everything is very different from the other kind of strands of science because pure development is chemistry, pure toxicology is biological. A lot of development of semiconductors and stuff, that's all physics based whereas nano exists in all of the three main disciplines. [...]. It's unique in that sense'.	Describing N&N as an independent area of research	
'I get the feeling that there is an increasing identification, it's not just nano but it's particularly in nano and almost maybe a pride as well. We're not physics. Not just in the nano-field but in other area as well, there is an increase of interdisciplinary. So I get the feeling that this increase we get in general pride that: we're not physics, we're not chemistry, we're interdisciplinary'.	Developing a proper identity	
'I'm registered with the school of physics so I'm on paper I'm a physicist now but I'm a toxicologist really. I find it easy to talk to them all. My background is chemist so I consider myself as a chemist but because the Alpha group is part of the school of physics, so if someone would ask me where do you work I say the school of physics, so therefore I am a physicist. However I am not, I'm a toxicologist working in the school of physics. So I'm like a biologist who is actually a chemist but works in the school of physics'.	Having difficulties to be described when there are no established standards	**Confusion**
'People ask me what I do and it is really frustrating because if you say nanotechnology maybe 30%, 40% of people know what it is. But if you try to explain that I am a chemist but I use nanomaterials and I do physical things, measure them biologically and... They're kind of like Jesus no, she's confused, she doesn't know what she does'.	Justifying a multidisciplinary work	
'Hopefully after older kind of scientist, new researchers are coming and wouldn't have problem to work with one or another. It is not a personal things, it is political limits. With another student [...] that would be the same. We are chemist, so nobody wants to hire a chemist who has a PhD in biology because they're not a specialist'.	Being concern about finding a place with a multidisciplinary background	

5.5 DISCUSSION

This study was designed to answer the following research question: How do scientists involved in a scientific area crossing multiple scientific disciplines use multidisciplinary knowledge in order to create a new scientific outcome? This research is motivated by a need to deepen the understanding of scientific practices in a multidisciplinary context. Through an exploratory study, I looked at how scientists hosted by a single research group and with different scientific backgrounds practise multidisciplinarity in their day to day work. I first highlighted that the research group has developed a speciality in N&N based on internal capacities and stock of knowledge. Second, I showed that scientific boundaries are difficult to be crossed and lead scientists to create local knowledge in order to produce a multidisciplinary scientific outcome. Finally, by engaging in multidisciplinary practices on a daily basis, scientists and young scientists in particular are torn between being pioneer of a new scientific area and have difficulties to locate themselves in their environment. Considering the theoretical framework and the findings, the discussion will be based on two points: (1) scientific practices in a multidisciplinary context and (2) convergence of scientific disciplines, and technological hubs.

First, practices were defined as ‘equated with doing, concreteness, understanding, know-how and wholes’ (Weick, 2003: 454). In the multidisciplinary context of N&N, practices do not rely on the cumulative process of knowledge creation. Indeed, in a fast growing contexts, no basic body of knowledge have been clearly identified (Yanez et al., 2010). By bringing methods and theoretical knowledge from a scientific discipline to another, scientists create local knowledge. So, as practices are not predetermined by theoretical foundations, they are created on a daily basis. This knowledge is not part of the cumulative process as they have to be explained in depth in order to make sense and to be accepted in the other disciplines. So, although incorporated in instruments, knowledge accepted in a community has to follow a similar process in order to be accepted in another one. In their classification of scientific statements, Latour & Woolgar (1979) describe the process through which an observation (Type 1 statement) will be assessed in order to be accepted or not in the scientific community (Type 5 statement). The local practices, or knowledge (Weick, 2003), that are created by using instruments from a scientific discipline have to go through the similar assessment in order to be accepted in another discipline. Moreover, although sometimes scientists move from one discipline to create a new sub-discipline (Shinn & Ragouet, 2000), the lack of established channels (Zucker et al., 2007), in other words multidisciplinary journals, might hinder the theorisation of these types of new practices and knowledge.

Second, the convergence of scientific disciplines is limited and the collaboration them is at a more multidisciplinary stage than an interdisciplinary one (Schummer, 2004b). Indeed, as mentioned earlier, both the specialisation of the laboratory and practices rely on established scientific disciplines and no strong ties, overlaps and integration can be strictly identified. So, multidisciplinarity is more suitable in order to characterise the movement of scientists between different areas of research (Shinn & Joerges, 2002; Shinn & Ragouet, 2000) than a real interdisciplinarity in scientific research. This point is related to the limited multidisciplinarity aspect of N&N (Bassecoulard et al., 2007; Rafols & Meyer, 2007; Schummer, 2004b, 2009). Therefore, some overlaps exist between the parent disciplines and might lead to the creation of new sub-disciplines (Shinn & Ragouet, 2000) but the cross-fertilisation between the disciplines is not established enough to be named interdisciplinary research. However, all over the world micro- and nano-technology centres have emerged (Kautt et al., 2007). While we have focused here on a research-oriented research group, in the global context described by the triple helix model (Leydesdorff & Etzkowitz, 1998a; Leydesdorff & Meyer, 2007; Leydesdorff, 2000) more industry-oriented research groups and centres have also emerged (Kautt et al., 2007). We therefore question the boundaries that are set up by public funding in order to foster multidisciplinary research and the development of N&N materialised by research centres, and the scientific boundaries that are present within these research centres. Although traditionally physical boundaries of the research centres match the cognitive boundaries of science, there is now a mismatch between the two.

Knorr-Cetina (1992) argues that the configurations of laboratories are shaped in relation to the work which goes on within the laboratory. In other words, depending on the type of research the laboratory can take different forms. The relation between the laboratory – physical and social structure – and the experiments – type of science – can be more or less intertwined. So, building on Knorr-Cetina (1992) and by following (Kautt et al., 2007) description of research centres – technology, aims (research or industry-oriented) and types of funding – I here argue that technological hubs can be characterised in terms applying a set of composite boundaries (Hernes, 2004a, 2004b) in order to have a much more precise picture of the different types of laboratory that are dedicated to nanotechnology. This will allow us to highlight the different research groups and centres to deepen the understanding about which scientific disciplines are present within the research centre or group, the type of collaboration that is undertaken within and with the outside of the laboratory, and the structure that hosts the scientists. This should enlighten the different types of convergence and multidisciplinarity in N&N.

5.6 LIMITATIONS AND FUTURE RESEARCH

Three main limitations of the study are identified here. First, the research took place in a research group that has been chosen for its endogenous attributes (Siggelkow, 2007). It hosts scientists with various backgrounds and the specialisation of the research group is the area of nanotoxicology which is characterised by the integration of physical characterisation to biological studies. Therefore, this single case presents idiosyncratic characteristics that can be avoided by performing a multiple case study (Eisenhardt, 1989). However, this case brings empirical data to the understanding of the multidisciplinary aspect of N&N. Second, boundaries are not static but are in constant construction and reconstruction (Hernes, 2004a, 2004b). This study does not capture the evolution of the boundaries over time and how individuals challenge these boundaries. A more longitudinal approach has to be undertaken in order to clarify the evolution of collaboration in a multidisciplinary context. Third, the study focuses on scientific practices and does not fully take into account the funding and the expectations that are related to it which can influence the research and/or the specialisation of the lab.

5.7 CONCLUSION

This study contributes to a better understanding of the influence of policy makers on the emergence of a new scientific discipline by focusing on a research group qualified as technological hubs and that hosts scientists with various scientific backgrounds. It completes the macro-meso analysis by confirming the scientists from various backgrounds face boundaries that hinder the emergence of a common discipline. It also highlights the argument that structure of science is still very stable. Another insight to be gained from this study is that nanotechnology is at a multidisciplinary stage more than an interdisciplinary one. The collaboration between scientists from different disciplines can be understood by their scientific heritage and the barriers that are related to it, and how individuals use knowledge from another discipline in order to produce a new scientific outcome. It also suggests that nanotechnology can be further understood by focusing on co-existing boundaries and locus of multidisciplinarity.

Chapter 6.

Rethinking the nanotechnology revolution: A political construct against scientific and industrial inertias

6.1 INTRODUCTION

This last chapter discusses the general findings of this study and the generalizability of the cases in relation to three themes that were important in the evolution of N&N: the delineation of nanotechnology, new dynamics in science and the stability of extant paradigms. This pan-technology (Allarakhia & Walsh, 2012), which has impacted multiple scientific disciplines and industrial sectors, is supposed to have a high impact on society (Roco & Bainbridge, 2005). Indeed, this technology – or more precisely technologies – can be used to observe, manipulate, and control atoms within both organic and inorganic systems. This brings opportunities for applications in various areas, such as the medical sector with new drugs and their administration, cures for diseases, and biotechnology, but also micro-electronics, sensors, nanostructures, and so on. Because of its pervasive characteristics (Lo, Wang, Chien, & Hung, 2012), numerous applications are expected to stem from this technology.

The research activity within this area has grown faster in comparison with the average for science and engineering in general (Bonaccorsi & Thoma, 2007). The promises linked to that technology have grabbed the attention of the scientific community at the international level (Guan & Ma, 2007). These worldwide trends have been fostered by policy makers in leading countries, such as in the US with its National Nanotechnology Initiative that started in 2001 or in Europe with the integration of nanotechnology as a separate research stream for research in the Sixth and Seventh Framework Programmes. This technology has also grabbed the attention of the technology and innovation community with the publications of four special issues in *Research Policy* (Bozeman et al., 2007), *Technological Forecasting and Social Change* (Eijkel, Groen, & Walsh, 2007), *The Journal of Technology Transfer* (Shapira & Youtie, 2011) and *Technovation* (Mangematin & Walsh, 2012). These works have clarified the comprehension of the emergence of this technology and have deepened our understanding of it.

Three elements were particularly important in N&N. First, the boundaries of this technology have been particularly difficult to draw. Indeed, the involvement of multiple scientific disciplines and industrial sectors has renewed the debates on multi- and interdisciplinarity, and on convergence. Second, the important involvement of government in the financing of this area has questioned and still questions the steering of science by policy makers and the extent to which they impact the dynamics of science. Third, in spite of the increase in the development of nanotechnology since the 1990s, business models – like scientific disciplines – have remained very stable. Then, based on three axes, I discuss nanotechnology as a political construct and the extent to which this technology is likely to be remobilised by established disciplines and industries and to fade out. Finally, future directions for research in relation to the evolution of the role of scientists as principal investigators and the rise of project management in science are presented.

6.2 GENERALIZABILITY OF THE CASES

The six cases in this study are embedded in different streams of research: toxicology and pharmacology for Alpha and Beta, theoretical physics for Gamma and material science for Delta, Epsilon and Omega. Alpha and Beta are the teams that engaged the most in N&N with scientists from various backgrounds, an intensive use of the word nano in their publications, and the reconfiguration of infrastructures. The four other cases were more monodisciplinary teams and reconfigured to a lesser extent their social and physical boundaries. Alpha and Beta are also the only teams that dealt with living systems and the biology community at large. This leads to question of the impact of nanotechnology on different areas of research.

The degree of involvement and embeddedness between the cases in nanotechnology echoes two lines of argument in the literature. One the one hand, although nanotechnology began in the 1990s and its development has accelerated in the 2000s, transformations have, for the moment, been mostly incremental (Kautt et al., 2007; Shapira & Youtie, 2011). Indeed, nano-instruments enable the improvement of chips, sensors, processors, and so on but have not led to a so-called revolution. On the other hand, studies argue that radical changes are most likely to occur in the bio area. However, this domain is still in its infancy (Juanola-Feliu, Colomer-Farrarons, Miribel-Català, Samitier, & Valls-Pasola, 2012). Although it is very difficult – even not possible given the multiplicity of factors – to predict the emergence of new disciplines, some studies provide directions to look at, such as the bio area (Allarakhia & Wensley, 2007; Shapira, Youtie, & Kay, 2011).

Even though cases are not generalisable given the idiosyncrasies of the individuals, organisations and of the context, comparing similarities and dissimilarities enable to relate the cases with other studies. Multidisciplinary teams produce more heterogeneous outcomes (Porac et al., 2004) and, given the multiplicity of disciplines involved, are more likely to reach a radical breakthrough (Wry et al., 2011). In that sense, Alpha and Beta relate to this type of teams and to the areas identified by the literature has promising for radical innovations. The four other cases are more monodisciplinarity teams (Porac et al., 2004) that more are likely to produce incremental transformations. The emergence of new areas also depends on the way in which the definition of nanotechnology evolved and is remobilised by extant disciplines.

6.3 AN UNFINISHED BOUNDARY WORK

Drawing the boundaries around nanotechnology is not an easy endeavour given the multiple actors that are impacted by this technology. However, it is an important step to understand the paths from where it is coming (Porter, Youtie, Shapira, & Schoeneck, 2008). Nanotechnology can be primarily described as the research and development of technologies and applications within the range of 1 to 100 nanometres (Gokhberg, Fursov, & Karasev, 2012). This implies the ability to control and to manipulate matter at the atomic level in order to build novel molecules and/or structures and to use their properties (Bonaccorsi & Thoma, 2007). However, as there is no strong line of demarcation between, for instance, a 100 and 120 nm, nanotechnology deals more with the manipulations of atoms to produce manmade structures, and the use of the novel properties that matter shows at that scale (Kostoff, Koytcheff, & Lau, 2007).

This ability to manipulate atoms is very generic and finds applications in many scientific disciplines (Zucker et al., 2007). This makes the delineation of the technology and of an emerging field difficult as the outcomes cross multiple scientific boundaries. However, the crossing of scientific boundaries does not necessarily imply the convergence of the disciplines using nanotechnologies. Different studies have shown that the structure of scientific disciplines has remained very stable, even though word has spread out within the disciplines (Heinze & Bauer, 2007; Rafols & Meyer, 2007).

The convergence of multiple disciplines and the construction of strong relationships and common areas of research between them did not occur in a clear way (Schummer, 2004b). Although the convergence has been largely emphasised by policy makers (Porter & Youtie, 2009a), scientometric studies tend to balance the phenomenon. Bassecoulard, Lelu and Zitt (2007) show that, at the field level, physics and chemistry are the leading disciplines. Moreover, the level of interconnectedness seems to be more an apparent feature (Heinze & Bauer, 2007; Rafols & Meyer, 2007), which is due to the sharing of the prefix nano (Schummer, 2004a, 2004b). The expansion of the prefix nano (Grodal, 2010) shows an artificial convergence, but does not reflect an actual change of the deep structure of science. The lack of consensus around and precision in the definition of this technology allows this umbrella term to host multiple, and sometimes opposite paradigms, which hinders the integration of the disciplines (Schummer, 2004b).

At the article level, the picture of barely related areas is more balanced. Cited articles in nano-publications show a greater level of interdisciplinarity (Bassecoulard et al., 2007), where knowledge is coming from various disciplines (Meyer & Persson, 1998). In that sense, research at the nanoscale tends to be more and more integrative (Porter & Youtie, 2009b). These studies hardly give an idea of where the convergence occurs and show that the established scientific disciplines have not converged to the extent to form a new paradigm. Even though the cognitive structure of science has not been shaken by the rise of nanotechnology, transformations happened on other loci. First, nanotechnology, as a general purpose technology, has enabled the renewing of existing disciplines, such as the introduction of engineering within biotechnology to form the new area of nanobiotechnology (Fortina, Kricka, Surrey, & Grodzinski, 2005; Hacklin, Marxt, & Fahrni, 2009). Second, with the transformation of the organisation of science and the push towards application-oriented research, change has also occurred with the convergence of different actors around a specific issue, such as biosecurity (McLeish & Nightingale, 2007). Although they were both expected to be revolutions, nanotechnology differs from biotechnology in terms of the reshaping of boundaries.

These two technologies share common features and are often compared with each other to study the multidisciplinarity characteristic (Rafols & Meyer, 2007): how knowledge permeates the different disciplines involved (Grodal & Thoma, 2008), how technology is transferred to industry (Genet, Errabi, & Gauthier, 2012), their convergence (No & Park, 2010), and so on. Moreover, they are both new methods of inventing (Rothaermel & Thursby, 2007; Thursby & Thursby, 2011b) in the sense that they facilitate breakthrough discoveries (Darby & Zucker, 2003). However, nanotechnology differs from biotechnology in terms of structuration of the field. Indeed, nanotechnology can hardly be considered a discipline or an emerging discipline as suggested by studies on its delineation through various attempts at establishing a definition or through citation analysis to identify the parent disciplines and the degree of multi- and interdisciplinarity. These works describe – although non-directly – the persistence of invisible colleges in science.

Invisible colleges refer to a small group of scientists who tend to cite each other, even though they are not linked by formal organisational ties (Crane, 1972). These social groups maintain the stability of scientific communities as new entrants want to collaborate with them. In-group members are interconnected with one another to solve a particular problem that they have in common. The concept of invisible colleges suits the various studies and interpretations of the area of N&N. Indeed, notwithstanding the presence of nano-dedicated journals (Braun, Zsindely, Dióspatonyi, & Zádor, 2007) and facilities, N&N struggles to emerge as a discipline. Further, even though some areas gather multiple specialties, such as in bionanotechnology (Rafols & Meyer, 2007), most of the nano-dedicated journals publish articles with authors from only one disciplinary affiliation (Schummer, 2004a). Crane's (1967) work suggests that editors can act as gatekeepers who tend to support orthodox research, which would support the idea of the persistence of invisible colleges and the constancy of the established disciplines. Moreover, as collaborations involving a transfer of knowledge are not rewarded, interdisciplinarity might have failed the institutional support needed for a new science to emerge (Frickel & Gross, 2005; Jacobs & Frickel, 2009).

In that sense, even though new research avenues have emerged thanks to a wide array of possibilities open by nanotechnologies, boundaries have not been reshaped towards the same directions. While policy makers have largely based their action on expectations and reshaped some of the research infrastructure, scientific disciplines have not moved at the same pace. Even though scientists can align their applications with the call for funding to get financial resources, their practices remain embedded in the pace of their communities to gain legitimacy (Brown & Duguid, 1991). Focusing on the paces to which the different actors involved in the emergence of a new discipline evolve would enable to better describe the dynamics in science as well as their possible mismatches.

6.4 INSTITUTIONAL LOGICS AND DYNAMICS IN SCIENCE

Institutional logics are a suitable frame to study the different dynamics in science as they facilitate characterising the various communities – both scientific and non-scientific – that are involved when a change in dynamics occurs (Seo & Creed, 2002). This frame is even more relevant as policy makers involved in the steering of science (Whitley, 1984, 2007) and scientists themselves commercialise their knowledge through spin-off companies, patenting and licencing, or collaborations with industry (Fini & Lacetera, 2010; Louis et al., 1989; Rothaermel, Agung, & Jiang, 2007). Swan et al. (2010) describe how the logics promoted by policy makers competed with the prevailing logic and failed at changing practices as knowledge is both produced and legitimised within the old logic. Although attractive both for the scientific possibilities and the financial resources from public agencies, the N&N logic has not fundamentally reshaped the boundaries of science. While N&N has shaken the established categories of science, a massive convergence between these disciplines has not been observed. Indeed, while some actors clearly identify themselves with N&N, others have been more careful with their affiliation to this category (Granqvist et al., 2012; Grodal, 2010). Furthermore, some actors use the N&N category to span multiple extant categories (Wry, 2010). In that sense, N&N is more a means to improve established paradigms than an emerging phenomenon that triggers a massive rallying.

N&N has also been described as a general purpose technology (Gambardella & McGahan, 2010; Youtie, Iacopetta, & Graham, 2007) that spans multiple disciplines (Huang, Notten, & Rasters, 2011). A general purpose technology (GPT) is characterised by its pervasiveness, ability to produce innovation, and scope for improvement (Youtie et al., 2007). Various studies have described the extent to which nanotechnology crosses scientific boundaries (Allarakhia & Walsh, 2012; Bassecoulard et al., 2007; Olsen, 2009; Porter & Youtie, 2009b; Rafols & Meyer, 2007; Schummer, 2004b). Although these studies disagree over the extent to which nanotechnology has made disciplines converge, they show that nanotechnology has emerged in many fields and modified the global picture of science. In terms of innovation and improvement, studies show that innovations related to nanotechnology have been mostly incremental thus far (Fiedler & Welpe, 2010; Pandza, Wilkins, & Alfoldi, 2011).

Social science studies (Shapira, Youtie, & Porter, 2010) provides us with more understanding on the characterisation of what nanotechnology is and how it has impacted science. If nanotechnology has clearly been visible through the emergence of nano-dedicated companies and clusters (Mangematin, Errabi, & Gauthier, 2011; Robinson, Rip, & Mangematin, 2007), research infrastructure and a growing job market (Stephan, Black, & Chang, 2007), deep transformations within science are much more balanced (Battard, 2012). Although it would be fallacious to argue that nanotechnology does not exist and has not impacted science, it is important to clarify what nanotechnology has transformed. Through the frame of institutional logics, a clearer picture appears. Indeed, nanotechnology has benefited from a great deal of enthusiasm, which was mainly based on expectations instead of solid breakthroughs. Moreover, policy makers have massively invested (Roco, 2005) to support both research and industry in their development around this technology. The landscape around this technology has changed by transforming the infrastructure and, therefore, the material elements – structures and practices – of the new logic (Thornton et al., 2012). Practices, to a certain extent, have also been impacted along with the infrastructure, as, on certain projects, scientists from various backgrounds have converged around a common object, or even merely shared a common infrastructure. However, as specified by various studies that attempt to map out nanotechnology, the convergence is limited and the degree of interdisciplinarity debatable – except in very specific areas like bionanotechnology (Fortina et al., 2005; Rafols & Meyer, 2007; Roco, 2003). The cognitive and social structures of the established scientific disciplines – the symbolic elements of the old logics – have remained rather stable. Therefore, what is seen at the structural level does not reflect a fair picture of what happens at a more micro level.

So, in that picture, where does nanotechnology stand? Nanotechnology has massively emerged through the impulsion of public policies, first in the US, followed by Western countries and Asia. As these incentives have only been partially followed, what we have witnessed could be assimilated to a political construct, rather than a deep scientific transformation. We can go further by arguing that nanotechnology is going to be recovered by the established disciplines. The Eighth European Framework Programme (renamed Horizon 2020) supports this line of argument, as nanotechnology is no longer funded as a scheme – unlike the case for the Sixth and Seventh European Framework Programmes – but will now be considered as a key enabling technology (KET). Furthermore, the contrast between the level of funding and the results – compared to other countries such as the US – questions the importance given to this priority area:

> The case of nanotechnology is a perfect illustration of the negative impact of fragmentation of public resources on scientific and technological performance. In this key enabling technology, which is critical for future international competitiveness, the EU spends more public money annually than other developed or emerging countries. […] However, as highlighted in a recent Communication of the EC (2009), "despite these relatively high levels of funding, the EU is not as successful in deploying nanotechnology as for example the US, when looking at the ability to transfer knowledge generated through R&D into patents". (European Commission, 2011: 11)

However, it is worth highlighting that the disappearance of the funding does not mean the same for the technology. Indeed, nanotechnology has impacted multiple scientific disciplines and has opened a wide range of new possibilities. Thus, by investing in a technology, policy makers demonstrate support both for progress in fundamental science and for radical innovation in application-oriented research (Price, 1984). This technology bears the possibility both to challenge extant paradigms and to open new research avenues that may – or may not – lead to the emergence of new sub-disciplines. So, convergence may happen between two or more research specialties, but does not seem to be the major phenomenon. By comparison, the discovery of the double helix changed the biological paradigm and led to the emergence of biotechnology. It challenged the cognitive structure of biology. Nanotechnology, and to be more accurate, nanotechnologies are enablers that ease the confirmation or invalidation of established theories, improve extant and create new materials, and open up the doors of the atomic scale.

Studies of science, whether it be in sociology or philosophy, take the stand that drastic changes in science come from within science (see Frickel & Gross, 2005; Kuhn, 1970). We go further with this argument by bringing back the role of policy makers in the dynamics of science. Inner changes challenge the cognitive structure of disciplines by questioning the extant paradigms and, therefore, the theories on which research is based. However, if policy makers cannot directly influence the cognitive bases, they have the ability to modify the physical research infrastructure. As both the cognitive and material are tightly tied to form an institutional logic (Thornton et al., 2012; Thornton & Ocasio, 2008), by transforming the material elements, policy makers re-dynamise the domain of science. If the roles of policy makers are usually depicted as finding a balance in the steering of science, bringing support to potentially fruitful research avenues, easing technology and knowledge transfer between science and industry, and so on (see Bonaccorsi & Thoma, 2007; Bonaccorsi, 2008; Etzkowitz & Leydesdorff, 1999; Leydesdorff & Etzkowitz, 1996; Leydesdorff, 2000; Lundvall, 1988; Whitley, 2007), their role in bringing new dynamics in science is never directly pointed out. By being able to move the scientific infrastructure, policy makers can bring new dynamics to established disciplines without disrupting their core assumptions.

6.5 STABILITY OF BUSINESS MODELS

The emergence of new business models has been a key element to the disruption of the drug development sector and the structuration of the biotechnology field (Nosella, Petroni, & Verbano, 2005; Sabatier, Kennard, & Mangematin, 2012; Sabatier, Mangematin, & Rousselle, 2010) and a similar questioning can be asked about the structuration of the nanotechnology industry (Mangematin & Walsh, 2012). Business models are a conceptual description of a business, how it is organised and structured, and how value is created and captured (Baden-Fuller & Morgan, 2010; Teece, 2010). Business models are essential in the exploitation of a new technology, as the way in which the organisation integrates this innovation will influence the way the technology emerges (Chesbrough, 2010). The concept encompasses the various elements that are necessary to the business – and its renewal – from the exploitation of a single business to a business model portfolio (Sabatier, Mangematin, & Rousselle, 2010). New entrants have the ability to disrupt a dominant logic – along with incumbents' business models – and to bring a high level of turbulence into an established field (Tushman & Anderson, 1986). Radical technological changes occur when a dominant logic is challenged and new logics are competing with each other. Once a logic becomes dominant, more incremental innovations take place (Anderson & Tushman, 1990). As nanotechnology crosses many sectors, is the disruption of multiple industries expected?

Unlike in biotechnology, incumbents have played a major role in the industrial development of nanotechnology (Mangematin et al., 2011). Moreover, while smaller firms integrate nanotechnology within patents and publications, larger firms tend to exploit nanotechnology in patents embedded in separate established fields (Avenel et al., 2007). Additionally, Zucker et al. (2007) show that nanotechnology follows more a cumulative than disruptive knowledge production model. In that sense, nanotechnology does not disrupt dominant industrial logics, but is integrated at different points of the value chain to support both extant technologies and processes (Rafols, Zwanenberg, Morgan, Nightingale, & Smith, 2011; Rothaermel & Thursby, 2007; Zucker et al., 2007). So, as Tushman and Anderson (1986) argue, technological change initiated by incumbents tends to enhance, rather than destroy, knowledge and competences and triggers lower turbulences. In that sense, if nanotechnology has not disrupted incumbent positions, it has enabled – and to a certain extent forced – them to renew their stock of knowledge (Doz & Kosonen, 2010; Linton & Walsh, 2008).

As a general purpose technology, nanotechnology crosses multiple industries and supports – or at least shakes without destroying – their dominant logics. This stability and relatively low turbulence within industry – in spite of the hype supported by policy makers – lead to discuss nanotechnology as a revolution. Indeed, even though nanotechnology shows some promising radical innovations in applications with biological systems (Allarakhia & Wensley, 2007; Shapira et al., 2011), nanotechnology seems more likely to be remobilised by extant disciplines and industries and to fade out than to be at the inception of new fields. This by no means signals the disappearance of nanotechnology, but rather the continuity of new possibilities enabled by technological evolution. If the cumulative knowledge production model remains effective (Zucker et al., 2007), it might have been accelerated by nanotechnology and its possibilities to cross many disciplines and industries.

6.6 A POLITICAL CONSTRUCT AGAINST SCIENTIFIC INERTIAS

Nanotechnology as a general purpose technology challenges the multiple technological areas in either an incremental or radical way. Even though it did not lead to a massive convergence of physics, chemistry, and biology, it gave the possibility to open up new areas of research such as nanomedicine, nanotoxicology, and drug delivery. The three themes developed here support the argument that nanotechnology, as a GPT, has not emerged as a new scientific discipline or industry. It however questions the influence of policy makers on science: First, what is the role of policy makers if their actions do not trigger deep changes in science? And, second, do scientists and firms have to listen to them? Diverse studies on nanotechnology show little, if any, change to the deep structure of science (Bassecoulard et al., 2007; Schummer, 2004b) and that this technology is mostly incremental (Shapira & Youtie, 2011). The use of keywords may look like the emergence of a new area (Schummer, 2004b), but some extant areas have been relabelled rather transformed (Granqvist et al., 2012). If policy makers cannot trigger change, policy makers go more towards having a supportive than steering role.

In spite of the limited impact that policy makers can have on science, they have the power to provide scientists with the necessary financial support and to set grand directions. Moreover, they provide science with a link to society, an element which cannot be ignored. Science counts among its goals social welfare, economic growth, and the generation of knowledge for the sack of knowledge. Even though it is difficult when the economy is stumbling, long-term perspective in science should not be left out the science and technology policy’s priorities. A great instance of these long term investments is the CERN experiment, which started over 50 years ago and led to the quasi proof of the Higg’s boson. Although the end gaols are theoretically or empirically not reachable yet, having a long-term orientation is also what stimulates science. When Feynman (1960) made his famous talk ‘There’s plenty of room at the bottom’, the word nano had not been used yet and the possibility to manipulate atoms one by one was only theoretical.

Nanotechnology has crossed boundaries and has yielded possibilities to enhance existing materials or to create new ones. This line of argument leads to discussing the politically-constructed nature of nanotechnology. Nanotechnology has been promoted worldwide and in Europe at both the national and supranational level. At the beginning of the 2000s, agencies such as the NNI in the US and the European Commission have largely enabled the diffusion of this technology across disciplines, and its transfer to the market. However, this ‘nano’ wave matches the pace at which the technology has developed. Indeed, since the discovery of scanning tunnelling in 1981 and the atomic force microscope in 1986, innovations have mostly been incremental and the nanotechnology revolution is still expected. The buzz created by policy makers may have even emphasised the use of the word ‘nano’ and, therefore, artificially increased the number of publications related to this area. However, as nanotechnology has opened a great amount of possibilities, we should pay more attention to the different sub-areas of research, such as nanobiotechnology or the convergence of ICT with medicine, as they are likely the building blocks of industrial or societal revolutions.

6.7 DIRECTIONS FOR FUTURE RESEARCH

This study of the influence of policy makers on the emergence of a new scientific discipline describes that powerful actors have a greater impact on physical boundaries than on social and mental boundaries and that old and new logics can co-exist by decoupling their physical, social, and mental boundaries. This decoupling was also observed at the micro level with the barriers than scientists can face within a multidisciplinary laboratory. This was discussed along with the various studies that have been done on nanotechnology to show that the political wave that supported this technology from the 1990s does not reflect the development and the possible revolutions enabled by this technology. This study brings new insights to pursue research in both the field of organisation studies and of technology and innovation management.

By using the lens of institutional logics through a composite boundary framework, this work pushes further the analyses of coexistence between logics (Goodrick & Reay, 2011; Lounsbury, 2007; Marquis & Lounsbury, 2007). Even though these works bring more understanding of a field's dynamics, how organisations deal with multiple logics and, more importantly, how organisations adapt to environmental change has been overlooked. Recent studies (Kodeih & Greenwood, 2013; Pache & Santos, 2010) show that both the changes occurring in the environment and the organisational responses must be considered to understand how organisations survive these changes. Further complexity is added when a logic must be preserved, as is the case with hybrid organisations. Hybrid organisations combine multiple logics at their core. They are specific in the sense that tensions can arise between the different logics (Glynn, 2000). With their study of hybrid organisations, Battilana and Dorado (2010) show how these types of organisations can sustain competing logics by creating a common organisational identity. Sometimes, institutional constraints are so powerful that satisfying one logic leads to undermining the other (Pache & Santos, 2010). These recent studies show that coexistence of logics tends to be more the norm than the exception (Lounsbury & Boxenbaum, 2013).

First, with the transformation of the scientific activity, the role of principal investigator (PI) is becoming more and more important (Mangematin, O'Reilly, & Cunningham, 2012). Indeed, although scientists are embedded in a scientific community and produce knowledge within it, they also have to write grant proposals within which they must underline the societal and economic impacts of their research, develop applications with industrial partners, and so on. These other spheres further challenge the boundaries of science and push scientists to face multiple logics. Beyond nanotechnology, the way science is conducted has kept on changing and is still evolving (Whitley, 2007). This evolution has, among other changes, led to the emergence of a new role for scientists, namely that of principal investigator, and of project-based organising. Projects have arisen into science over the past decades due to the transformation of the scientific activity. The interrelationships between science, industry and the state have increased (Bonaccorsi, 2008; Leydesdorff & Etzkowitz, 1996) and, therefore, transformed the way in which science is performed. Recurrent financial resources have largely diminished alongside an increase in project-based funding (Laudel, 2006a). Project-based funding implies that scientists must manage both the production of new knowledge and the submission of calls for funding to guarantee a minimum of financial resources for personnel, such as postdoctoral researchers and PhD students, and equipment. Although both scientists becoming principal investigators (PIs) and the transformation of the scientific activity have been the object of numerous studies, the two have largely been studied separately. On the one hand, studies have focused on the rise of entrepreneurial science, for example, the different types of possible entrepreneurship (Louis et al., 1989), the different practices among PIs (Casati & Genet, 2012), the way in which PIs transform their environment (Mangematin et al., 2012), and so on. On the other hand, various authors have focused on the blurring of the boundaries at the macro level between governments, science and industry (Leydesdorff & Etzkowitz, 1996, 1998b). However, even though some studies make explicit the increase in managerial tasks that fall onto scientists (Etzkowitz, 1998; Laudel, 2006a), the deep transformations of the role of scientists led by the increase of project-organising within science has been overlooked.

Second, focusing on project-based organising and on PIs would help to fill this gap. The variety of theoretical lenses in the project-management literature offer complementary views to understand the evolution of projects, but lack empirical study (Söderlund, 2004). The transformation of the scientific activity offers fruitful fieldwork, as the project has become the main means through which to conduct research and gather financial resources. Scientific projects are not closed and isolated (Aubry, Hobbs, & Thuillier, 2007; Engwall, 2003) from scientific organisation and the environment, as they must be of relevance both for the scientific community in order to provide content for publications and for policy makers to get funding. While studies on this phenomenon mostly emphasise either the macro transformations or the PI himself/herself, less is understood about the extent to which the rise of the project within science transforms the role of scientists and, to a larger extent, the activity itself. Moreover, PIs are the link between science and governments, and science and industry, as they shape new research avenues, formulate new promises, align the interests of various actors, and so on. PIs are essential for science as, beyond their role of scientists, they shape the new boundaries of science and are the leading actors of change.

6.8 CONCLUSION

The study of nanotechnology in Ireland from the late 1990s onwards has facilitated enhancing our understanding of the extent to which multiple actors involved at the inception of a field are renegotiating their own boundaries and shaping new ones. Using a composite boundary framework allowed to highlight both the macro and micro dynamics that occur during this crucial phase of field emergence. At a theoretical level, powerful actors are able to restructure physical boundaries by setting up new organisations, but their impact is rather limited when it comes to social and mental boundaries. It shows that the coexistence of multiple institutional logics occurs with a decoupling of the physical and symbolic elements of each logic. Moreover, it shows that coexistence seems to be more the norm than the exception to understanding field dynamics. Additionally, scientists with backgrounds from multiple scientific disciplines and holding different logics face these social and mental barriers, which are difficult to overcome. Nanotechnology is a fruitful field of study as by crossing multiple disciplines and industrial sectors, it furthers the theory and triggers new research avenues in both organisational studies and technology and innovation management.

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Appendices

APPENDIX A: CURRICULUM VITAE

Nicolas Battard
ICN Business School
3 place Edouard Branly
57070 Metz Technopôle
France

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RESEARCH INTERESTS

My research interest lies in the phenomena of emergence and intertwinement of multiple logics. My PhD focused on the emergence of a new scientific discipline under the influence of policy makers. I am pursuing the study of the scientific activity by focusing on principal investigators and am also interested in family businesses. To do so, I mobilise different streams of literature in management studies such as institutional logics and composite boundaries. Empirically, my research is based on qualitative methods and mainly relies on interviews and document analysis.

KEY COMPETENCIES GAINED

- Qualitative methods
- Strong academic background in organisation theory, strategy and innovation
- Strong multidisciplinary focus on management and sociology of science
- Communication and project management skills

EDUCATION

2012 to present: **Assistant professor**, ICN Business School, Metz, France
2008-2013: Ph.D. in management, Dublin Institute of Technology, Dublin, Ireland
2006-2008: Research Master's Degree - IAE, Grenoble, France (with honours, first of the cohort)
2004-2006: Bachelors in Management and Economics – IUT 2, Grenoble, France

PUBLICATIONS

Battard, N. and Mangematin, V. 2013. Idiosyncratic distances: Impact of mobile technology practices on role segmentation and integration. ***Technological Forecasting and Social Change***, 80(2): 231–242.

Battard, N. 2012. Convergence and multidisciplinarity in nanotechnology: Laboratories as technological hubs. ***Technovation***, 32(3-4): 234-244.

PRESENTATIONS

Battard, N. and Robin, C. 2013. Understanding project as a nexus of convergences: An enabler and a boundary spanner. ***29th EGOS Colloquium***, July 4-6, Montreal, Canada: EGOS.

Battard, N., Donnelly, P. and Mangematin, V. 2013. Understanding the emergence of new institutional logics: A boundary story. ***29th EGOS Colloquium***, July 4-6, Montreal, Canada: EGOS.

Battard, N., Donnelly, P. and Mangematin, V. 2012. Creating and Sustaining a Scientific Specialty: A Sensemaking Sensegiving Approach. ***4th International Symposium on Process Organization Studies***, June 21-23, Kos, Greece: PROS.

Battard, N., Donnelly, P. and Mangematin, V. 2012. Integration of multiple stakeholders in scientific research: A sensemaking-sensegiving approach. ***28th EGOS Colloquium***, July 5-7, Helsinki, Finland: EGOS.

Battard, N. and Robin, C. 2011. Boundaries within an unbounded area: Alignment and unalignment in nano laboratories. ***27th EGOS Colloquium***, July 7-9, Gothenburg, Sweden: EGOS.

Battard, N. and Robin, C. 2011. Boundaries within an unbounded area: Understanding career space in nanotechnology. Presentation at the ***Winter School on Emerging Technologies***, March 30 – April 1, Pinsot, France.

Battard, N. 2010. New paradigm or new label: The case of nanotechnology. Presentation as part of the symposium 'Trajectories of technology emergence: From convergent technologies to distributed legitimacy' organised by Michael Lounsbury and Vincent Mangematin. ***Academy of Management Conference***, August 6-10, Montreal, Canada: AOM.

Battard, N. 2010. New paradigm or new label: The case of nanotechnology. ***26th EGOS Colloquium***, July 1-3, Lisbon, Portugal: EGOS.

Battard, N. and Donnelly, P. 2009. Can I be a specialist in nanotechnology?. Presentation at the ***NanoBio Conference***, October 15-16, Dublin, Ireland.

Battard, N., and Mangematin, V. 2009. Idiosyncratic distances: Practices around mobile technologies. ***Academy of Management Conference***, August 7-11, Chicago, United States: AOM.

Battard, N. 2009. Professional identity construction in emerging fields: The case of nanotechnology. Summary of PhD proposal presented at the ***PhD Workshop at the 25th EGOS Colloquium***, June 30 – July 1, Barcelona, Spain: EGOS.

ONGOING PAPER

Battard, N. and Robin, C. Transformation of the role of scientists: The rise of project-based organising in science. (Under the 1st round review in the *International Journal of Project Management*).

SERVICE TO THE COMMUNITY: REVIEWING

- Technological Forecasting and Social Change
- Technovation
- Academy of Management Conference

TEACHING EXPERIENCE

Corporate strategy **Master level**

Construction of a competitive advantage

- Business level and corporate level strategies
- VRIO framework

Organisation theory **Postgraduate level**

How to take a decision in a complex environment

- Basics and history of organisation theory
- Challenges of contemporary organisations

Innovation management **Postgraduate level**

What innovation is and its centrality for established firms and start-ups

- Innovation processes
- Integration of innovation into organisation's strategy

PROJECT EXPERIENCE

Research master's dissertation **February to September 2008**

GRENOBLE UNIVERSITY – Grenoble, France

- Research question: 'To what extent organisational identity can highlight the diversity of interactions between organisation's members and organisation's stakeholders?'
- Qualitative study carried out on work integration social enterprises (WISEs) in Grenoble

Project management – Qualitative and quantitative research **September 2007 to March 2008**

GRENOBLE UNIVERSITY – Grenoble, France

- Research question: 'What are the motivations and constraints in the adoption of sustainable energies?'
- Conducting unstructured and semi-structured interviews
- Determining typology of potential consumers

Master's dissertation (1st year) **April to June 2007**

GRENOBLE UNIVERSITY – Grenoble, France

- Research question: 'How do companies include CSR in their strategy?'
- Analysis of social reports across industries over time

WORK EXPERIENCE

IT assistant **September 2007 to September 2008**

IAE – Grenoble, France

Strategic management intern **April to June 2007**
CENTRE D'ETUDES ET DE RECHERCHES APPLIQUEES A LA GESTION (CNRS) – Management Science Laboratory - Grenoble, France

- Organisation of the 5th ADERSE conference (Association pour le Développement de l'Enseignement et de la Recherche sur la Responsabilité Sociale de l'Entreprise – Association for Teaching Methods and Research into Corporate Social Responsibility)

Business development consultant **May to June 2006**
SAGA FORMATION – Grenoble, France

- Implanting a business development tool
- Taking part in business development in mechanical sector
- Implanting a communication plan

Financial analyst **May to June 2005**
BANQUE DE FRANCE – Chambéry, France

- Analysing balanced sheets
- Rating companies

SKILLS

Languages

- French: mother tongue
- English: fluent
- Spanish: intermediate

Computer literate

- MS Office: Word, Excel, PowerPoint, Access
- MS Project
- SPSS (quantitative research software), Nvivo 10 (qualitative research software)

REFERENCES

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APPENDIX B: SOCIAL SCIENCE PERSPECTIVE ON NANOSCIENCE AND NANOTECHNOLOGY

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Dublin Institute of Technology
Camden Row
Dublin 8, Ireland

As part of the PhD research programme at the Dublin Institute of Technology, this study aims at deepening the understanding of the dynamics and evolution of the area of nanoscience and nanotechnology.

RATIONALE

Nanoscience and nanotechnology (N&N) are considered to be enabling and converging fields that are said to be one of the key developments of the 21st century. Through an expansion of the label ‘nanotechnology’, multiple sciences are gathered under this umbrella term. These diverse sciences collaborate together in order on one hand, to understand the specific properties of the nanoparticles and contribute to the scientific knowledge and on the other hand, to make new medical devices, more resistant materials and more efficient transistors among an unlimited number of other possibilities that are likely to change number of industries. Recognising these scientific and economic potentials, public agencies and companies are massively investing in the development of N&N.

From the perspective of organisation studies, the area of N&N presents a lot of characteristics that are not fully understood as yet. Indeed, as nanotechnology crosses multiple disciplines, scientists with various backgrounds are led to collaborate in order to write scientific articles and grant proposals. Moreover, boundaries between science, industry and public agencies are blurred which makes relations between these entities more complex on one hand, and might create tensions between the goals to be achieved by the individuals working in this area on the other. N&N is of interest to social scientists in terms of managerial and economic questions including the role of public agencies and the dynamics that structure the scientific community but is also of interest to ‘hard’ scientists and laboratories in terms of career and positioning in the field.

STUDY

Theories and objectives

The study operates at two levels. The study will first focus on the impacts of public agencies on scientific disciplines. Indeed, massive funding oriented towards more multidisciplinary and application-oriented research has been poured in this area. In this way, through grant proposals, scientists influence research programmes. So, this first level of analysis aims at deepening the understanding of the extent to which public agencies influence scientific disciplines. The second level of analysis focuses on the boundaries that constrain scientists’ careers. Indeed, careers are less constrained by organisational boundaries than they used to be, but are more based on the competencies that an individual develops. In science, knowledge and expertise are essential in the sense that that is the way in which scientists are reckoned and acknowledged. This level of analysis focuses on how scientists make sense of the boundaries in N&N and manage them in order to invest in their career.

The core theme of the study is how to manage multidisciplinary communities in scientific area in order to understand the dynamics of a scientific community and the role that plays in guiding organisations in managing a scientific community.

Methodology and ethical process

A comparative case study has been adopted. To do so, laboratories dedicated to nanoscience are targeted. Different sources of data are required for the study. **First**, different documents that define the strategies and orientations that funding agencies adopted in order to fund science such as multidisciplinary, application-oriented research. This is to identify the boundaries that are drawn by policy makers. **Second**, newspaper articles, meeting minutes and internal documents (if possible) are gathered in order to define the strategy that the organisation established and its position in the area of nanotechnology. Through these sources of data, the PhD student will be able to define the organisations that were built up with a focus on nanotechnology and those that modify their strategy or spread their focus. **Third**, interviews will be conducted.

The interview will last about an hour. The themes that I would like to discuss with you are:

1. The career of the scientists and the reasons why she/he came to the area of nanotechnology.
2. The balance between fundamental and applied research, writing grant proposals, etc.
3. The vision of the organisation in the area of nanotechnology.

The interview guide will be slightly adapted in accordance with the position of the interviewee (professor, postdoctoral researcher, PhD student, manager, etc.)

It is important to note, that as the study focuses on the social side of the area of N&N work, no questions about the research *per se*, scientifically speaking, will be asked.

Moreover, if the interviewee agrees to record the interview, it will be transcribed and you will be able to correct any part of it. Thereafter, all data are anonymous. A form will be filled in before each interview in order explain the study and to guarantee the ethics of the process. These points of awareness, correction of the data and anonymity are part of the ethical processes required by the Dublin Institute of Technology.

RESULTS AND DISSEMINATION

Expected results of this study are the characterisation of the dynamics that structure the area of N&N. Firstly, the study will describe in which ways and to what extent policy makers impact on scientific disciplines and research programmes, and how laboratories and individuals adapt their work to these directives. Secondly, a characterisation of the boundaries will be made in order to understand the mechanisms through which scientists cross these boundaries and develop their career.

The dissemination of the results will be made in two ways. First, as part of the PhD programme in social science, the results will be oriented towards the social science community to theoretically explain the evolution and the structuring of N&N in order to renew scientific approaches of management innovation. Second, the results will also be oriented towards the community of N&N by giving to the members of this community a social science view of the area they are involved in.

APPENDIX C: INTERVIEW GUIDE

Personal trajectory

1. Can you describe your path (from graduate studies)?
2. Why did you choose to come to this area of science? How did you make your choices? Was there a person or an organisation that guided your decision? (Which person or organisation guided or still guide your choices?)
3. Is there any person or organisation that hindered your projects or goals – or might in the future?
4. Does nano create opportunities for your career?

Collaboration and work

1. What is the core of your research?
2. Can you describe the work you are doing at the minute? Is it multidisciplinary? Which scientific discipline are you in?
3. Where do you receive funding from?
4. Which journals are you targeting? The ones you are citing? Who choose the journal? (examples)
5. Which conferences are you going to? Who choose the conferences you're going to? (examples)
6. Who are your collaborators (experiments and papers)? Their discipline? Your relationships with them? (examples)

Nanoscience and nanotechnology

1. Why did you choose this laboratory?
2. Do you benefit from this organisation (equipment, people, etc.)?
3. Is there any other lab that you would like to go to?
4. Do you use nanotechnology in your work?

Position:
Degree: Year:
PhD: Year:
Gender: Age:

APPENDIX D: CAN I BE A SPECIALIST IN NANOTECHNOLOGY?

Nanotechnology can be considered as a converging technology. This means that a number of established disciplines, sectors, industries, fields, etc., are integrated around the same technology. Nanotechnology impacts different scientific disciplines, such as physics, chemistry, biology, electronics, and so on, and can be applied in order to make new medical devices, more resistant materials, and more energy efficient transistors, among an unlimited number of other possibilities. This has bridged multiple sciences around nanotechnologies and nanoinstruments in order to be able to characterise nanoparticles and, in a much broader way, nanomaterials. However, collaboration is not that easy for one’s professional everyday life is disturbed when one has to interact with somebody who is not part of one’s community. For instance, while one wants to work with parts per million, another would use milligrams or molarity; while one needs an absolute cleanliness and sterility, another can use the same pipette during the experiment, etc. By virtue of this diversity, it is difficult to consider nanotechnology as a matured scientific field for now. In this way, we wonder: how can a converging technology, such as nano, become a scientific field *per se*? We will first look at what a scientific field means.

According to Kuhn (1970), a scientific field is a community of scientists who share the same methods, practices, beliefs, and paradigms. Scientists put a lot of effort into defending their point of view and the assumption that scientists see the world as is like. Paradigms bound a scientific discipline in that they help scientists from the same community to formulate questions, select methods, define what is relevant or not, create meaning, and so on. From that perspective, being a specialist would mean someone who is an expert in these practices and methods and who embeds her/his work within a specific paradigm. Scientists from physics, chemistry or biology each have their own way of seeing and understanding the world and use different methods and practices in order to create meaning and relevancy in their own discipline. With nanotechnology, all these scientific disciplines cannot stay bounded anymore and have to collaborate in order to create further knowledge that will influence all disciplines. However, blurring boundaries between some disciplines does not mean not having boundaries anymore.

It is not obvious that a field can exist without boundaries. Scientific fields need boundaries in order to be able to find a common language, units, methods, practice in order to develop standards, rules, beliefs and for scientists to define themselves as a community. However, it remains difficult to identify boundaries while a field is still emerging and the core of this emerging field is a converging technology. Indeed, the history of science shows that scientific disciplines have always been divided rather than gathered together. Physics gave birth to atomic, laser and optical physics, materials physics, nuclear physics, etc.; chemistry to analytical chemistry, inorganic chemistry, materials chemistry; and biology to molecular biology, microbiology, toxicology, and so on. But with this converging technology, scientific disciplines are led to work together and break their boundaries instead of building yet more boundaries. Moreover, as nanotechnology is a converging technology, there are no common paradigms, beliefs, etc. behind it. So, in order to propose an answer to the future of the emerging field of nanotechnology, our interest is in following the careers of scientists involved in nanotechnology.

METHODOLOGY

From Mogoutov & Kahane's (2007) work, a database of journal papers has been compiled in order to provide a global overview of the field of nanotechnology. Results that follow have been extracted from this database according to the following criterion: at least one Irish-based author (determined by institutional affiliation) has collaborated in the paper. This resulting sample is a census of nanotechnology related publications over a period of 9 years (from 1998 to 2006). It comprises 1,966 publications, 4,291 authors, and 89 organisations. It is important to notice that among these authors, 2,848 have published only one article classified as “nano” over this period and the top 2 authors have published 89 articles. Authors who published the most have been selected in order to compare their publications classified as “nano” with all of their publications. CVs of these authors have been discussed with PhD students and postdoctoral fellows who are doing or did their PhDs in nanotechnology. Several elements come out of this dataset.

RESULTS AND DISCUSSION

First of all, we can distinguish two generations of scientists around this converging technology. On one hand, looking at the set of publications from scientists who have been doing research for decades, we can observe that their publications classified as ‘nano’ are not that far from their original discipline. More explicitly, we can say that this first generation has explored the nano dimension around a core discipline. There is no discernible disruption in their career whereby a drastic change in career can be observed. In a more or less natural way, also driven by technological discoveries, they moved to the area of nanotechnology. Nevertheless, even if their latest works are classified as ‘nano’, they still tend to consider themselves hard core scientists in their original discipline.

On the other hand, we then can identify a new generation of scientists. Given that the word nanotechnology existed already, that work at the nanoscale has already been done, and that it is now possible to do a PhD in the area of nanotechnology, the new generation of scientists are more sensitive to the possibilities and the cross-disciplinary dimension of nanotechnology. However, as we mentioned earlier, nanotechnology is a very broad area which makes converging multiple disciplines around the same topic. As such, given that it is quite impossible to get in-depth knowledge in all areas influenced by nanotechnology, new scientists gain general knowledge in different areas and develop skills in order to be able to communicate with and ask expertise from another other scientists from different disciplinary backgrounds. These skills, among other things, are developed thanks to being in close contact with different disciplines within the same project, such as a PhD.

Then, practices, methods, units, and so on are not homogenised, yet around this converging technology. Depending on the person the scientists interact with, the journals they are targeting, the projects they are working on, etc., the language, units of measurement, and protocols can be totally different. The main difficulty results in the fact that every discipline exists through its methods, practices, ways of saying what is relevant or not, etc. So, removing or transforming practices would lead, for some disciplines, to a loss of a part of their professional identity for a new one that is not yet well-shaped. From these first observations, we can now go back to the questions concerning the emergence of a field of nanotechnology and to the one related to the existence of a specialist in nanotechnology.

These questions are not unrelated. Indeed, is it possible to have a specialist within an unbounded area? Even if we cannot be specialist in an area that is not defined, different answers are however possible. A specialist in nanotechnology can be seen as a scientist educated in a core discipline, but who has general knowledge in a few other areas. Hence, this scientist would be able to communicate with others scientists in order to exchange knowledge and create new projects close to a specific area. This is what we have observed thus far. However, other possibilities may exist. A specialist in nanotechnology could also be seen as someone who has very broad knowledge in multiple areas with which s/he would be able to solicit and manage knowledge and people around a particular project, much like a knowledge purveyor. Even if this possibility does not really exist for now, it can be envisaged as the next step in the evolution of the field of nanotechnology. These are not the only ways of seeing a specialist in nanotechnology, but, in both cases, communication and exchange between disciplines are crucial.

Developing and establishing standards proper to nanotechnology would mean creating a new area that could exist independently of its parent fields and could improve the communication between scientists. However, a number of questions are raised by questioning such notions as ‘specialist’ and ‘field boundaries’: Where do boundaries have to stop? Which disciplines have to be integrated to the field? What am I a specialist in? Indeed, impacts of nanotechnology on human health and the environment have not been fully understood as yet. So, this questions the place of ethics and public perception. Do they have to be part of the common knowledge within the field or do they have to be an external body of regulation? All this questioning about boundaries is part of the next steps of the evolution of the field and the definition of who is a specialist in nanotechnology and who is not.

CONSEQUENCES OF THIS QUESTIONING

This questioning does not concern only a pure theoretical point in social science but has consequences on the future of science. In more practical terms, it is to understand if we are witnessing an aggregation around a technology or a new discipline. It first questions education. In the case of an aggregation, disciplines, and therefore schools, would be kept separated from each other. Students would have a major hard core science, with nanotechnology modules within the existing programmes. In the case of the emergence of a new discipline, this would completely change course designs. Students would have to integrate knowledge about what would be defined as nanotechnology. In other words, a programme entirely dedicated to nano. So, with a new discipline, could we envisage a faculty of science with a school of physics, chemistry, biology, and a school of nanotechnology? This questioning leads also to more general impacts.

Questioning boundaries leads us to understand what this dynamic is based on. In this way, we are wondering if it is based on a pure scientific logic or more than that. Worldwide governmental funding for nanotechnology has dramatically increased over the last decade (Roco, 2005). In order to get national or European funding, scientific projects have to be nanotechnology oriented. So through political decisions, scientific disciplines are pushed towards nanotechnology. In this way, we can wonder if nanotechnology escapes from scientific logic. If it does, what is the place of the scientific disciplines within this dynamic? While they have the expertise on the impacts of nanoparticles on human health and environment, questioning boundaries of the emerging field of nanotechnology also leads to questions of control and regulation, as well as the extent and limits of the applications of nanotechnology.

APPENDIX E: DETAILS OF TEAM’S PUBLICATIONS

Alpha’s publications from 2008 to 2011

All publications	**Number of publications**	**47**	
	Total of citations	**488**	
	Years of activity of the organisation	4	
	Citations per Publication	10.38	
	Citations per year	122	
	Citations per year per publication (mean)	2.84	
	Publications representing 50% of citations	7	
	Publications representing 75% of citations	16	
	Publications representing 80% of citations	18	
	Publications representing 90% of citations	26	
Articles mentioning *nano*	*nano* in the title	16	
	nano in the abstract	24	
	nano in keywords author	8	
	Number of publications	**25**	**53.19% of all publications**
	Citations	**284**	**58.20% of total citations**
	Citations per year per publication (mean)	2.94	(2.84 for all publications)
Articles not mentioning *nano*	**Number of publications**	**22**	**46.81% of all publications**
	Citations	**204**	**41.80% of total citations**
	Citations per year per publication (mean)	2.72	(2.84 for all publications)
WOS N&N category	**Number of publications**	**8**	**17.02% of all publications**
	Citations	**98**	**20.08% of total citations**
	Citations per year per publication (mean)	3.27	(2.84 for all publications)
Not WOS N&N category	**Number of publications**	**39**	**82.98% of all publications**
	Citations	**390**	**79.92% of total citations**
	Citations per year per publication (mean)	2.75	(2.84 for all publications)

Beta's publications from 2007 to 2011

All publications	**Number of publications**	**45**	
	Total of citations	**1859**	
	Years of activity of the organisation	5	
	Citations per Publication	41.31	
	Citations per year	371.80	
	Citations per year per publication (mean)	9.18	
	Publications representing 50% of citations	5	
	Publications representing 75% of citations	9	
	Publications representing 80% of citations	11	
	Publications representing 90% of citations	16	
Articles mentioning *nano*	*nano* in the title	40	
	nano in the abstract	35	
	nano in keywords author	22	
	Number of publications	**40**	**88.89% of all publications**
	Citations	**1838**	**98.87% of total citations**
	Citations per year per publication (mean)	10.2	(9.18 for all publications)
Articles not mentioning *nano*	**Number of publications**	**5**	**11.11% of all publications**
	Citations	**21**	**1.13% of total citations**
	Citations per year per publication (mean)	1	(9.18 for all publications)
WOS N&N category	**Number of publications**	**17**	**37.78% of all publications**
	Citations	**447**	**24.05% of total citations**
	Citations per year per publication (mean)	6.39	(9.18 for all publications)
Not WOS N&N category	**Number of publications**	**28**	**62.22% of all publications**
	Citations	**1412**	**75.95% of total citations**
	Citations per year per publication (mean)	10.87	(9.18 for all publications)

Gamma's publications from 2006 to 2011

All publications	**Number of publications**	**107**	
	Total of citations	**1508**	
	Years of activity of the team leader	6	
	Citations per Publication	14.09	
	Citations per year	251.33	
	Citations per year per publication (mean)	3.06	
	Publications representing 50% of citations	12	
	Publications representing 75% of citations	29	
	Publications representing 80% of citations	35	
	Publications representing 90% of citations	54	
Articles mentioning *nano*	*nano* in the title	17	
	nano in the abstract	25	
	nano in keywords author	8	
	Number of publications	**27**	**25.23% of all publications**
	Citations	**478**	**31.70% of total citations**
	Citations per year per publication (mean)	3.46	(3.06 for all publications)
Articles not mentioning *nano*	**Number of publications**	**80**	**74.77% of all publications**
	Citations	**1030**	**68.30% of total citations**
	Citations per year per publication (mean)	2.93	(3.06 for all publications)
WOS N&N category	**Number of publications**	**16**	**14.95% of all publications**
	Citations	**217**	**14.39% of total citations**
	Citations per year per publication (mean)	2.94	(3.06 for all publications)
Not WOS N&N category	**Number of publications**	**91**	**85.05% of all publications**
	Citations	**1291**	**85.61% of total citations**
	Citations per year per publication (mean)	3.09	(3.06 for all publications)

Delta's publications from 1999 to 2011

All publications	**Number of publications**	**73**	
	Total of citations	**586**	
	Years of activity of the team leader	13	
	Citations per Publication	8.03	
	Citations per year	45.08	
	Citations per year per publication (mean)	1.19	
	Publications representing 50% of citations	10	
	Publications representing 75% of citations	24	
	Publications representing 80% of citations	28	
	Publications representing 90% of citations	37	
Articles mentioning *nano*	*nano* in the title	**25**	
	nano in the abstract	**26**	
	nano in keywords author	7	
	Number of publications	**26**	**35.62% of all publications**
	Citations	**267**	**45.56% of total citations**
	Citations per year per publication (mean)	1.78	(1.19 for all publications)
Articles not mentioning *nano*	**Number of publications**	**47**	**64.38% of all publications**
	Citations	**319**	**54.44% of total citations**
	Citations per year per publication (mean)	0.87	(1.19 for all publications)
WOS N&N category	**Number of publications**	**6**	**8.22% of all publications**
	Citations	**46**	**7.85% of total citations**
	Citations per year per publication (mean)	1.4	(1.19 for all publications)
Not WOS N&N category	**Number of publications**	**67**	**91.78% of all publications**
	Citations	**540**	**92.15% of total citations**
	Citations per year per publication (mean)	1.18	(1.19 for all publications)

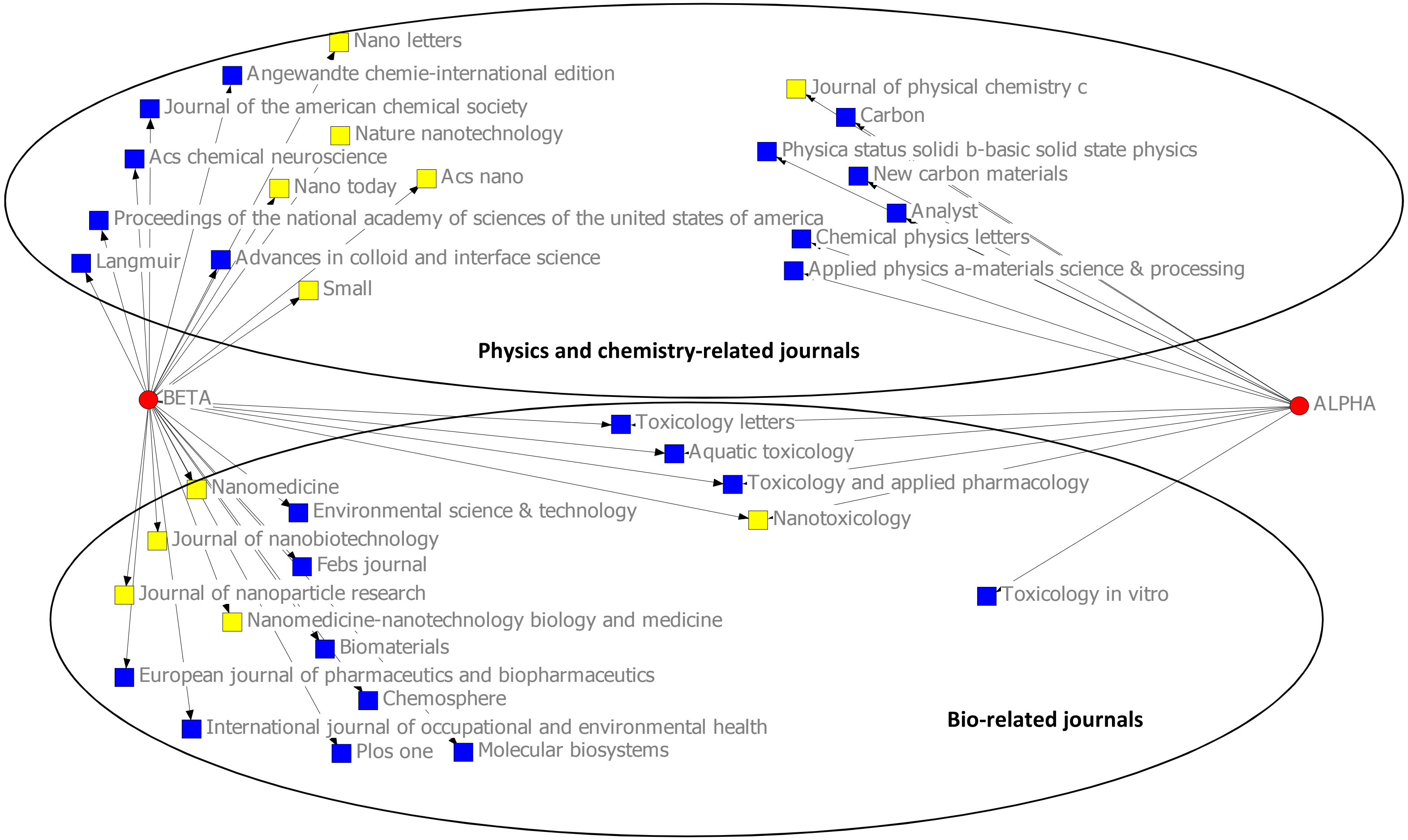
Epsilon's publications from 1999 to 2011

All publications	**Number of publications**	**66**	
	Total of citations	**714**	
	Years of activity of the team leader	13	
	Citations per Publication	10.82	
	Citations per year	54.92	
	Citations per year per publication (mean)	2.05	
	Publications representing 50% of citations	8	
	Publications representing 75% of citations	19	
	Publications representing 80% of citations	22	
	Publications representing 90% of citations	33	
Articles mentioning *nano*	*nano* in the title	3	
	nano in the abstract	3	
	nano in keywords author	1	
	Number of publications	**3**	**4.55% of all publications**
	Citations	**19**	**2.66% of total citations**
	Citations per year per publication (mean)	2.11	(2.05 for all publications)
Articles not mentioning *nano*	**Number of publications**	**63**	**95.45% of all publications**
	Citations	**695**	**97.34% of total citations**
	Citations per year per publication (mean)	2.04	(2.05 for all publications)
WOS N&N category	**Number of publications**	**11**	**16.67% of all publications**
	Citations	**78**	**10.92% of total citations**
	Citations per year per publication (mean)	0.94	(2.05 for all publications)
Not WOS N&N category	**Number of publications**	**55**	**83.33% of all publications**
	Citations	**636**	**89.08% of total citations**
	Citations per year per publication (mean)	2.27	(2.05 for all publications)

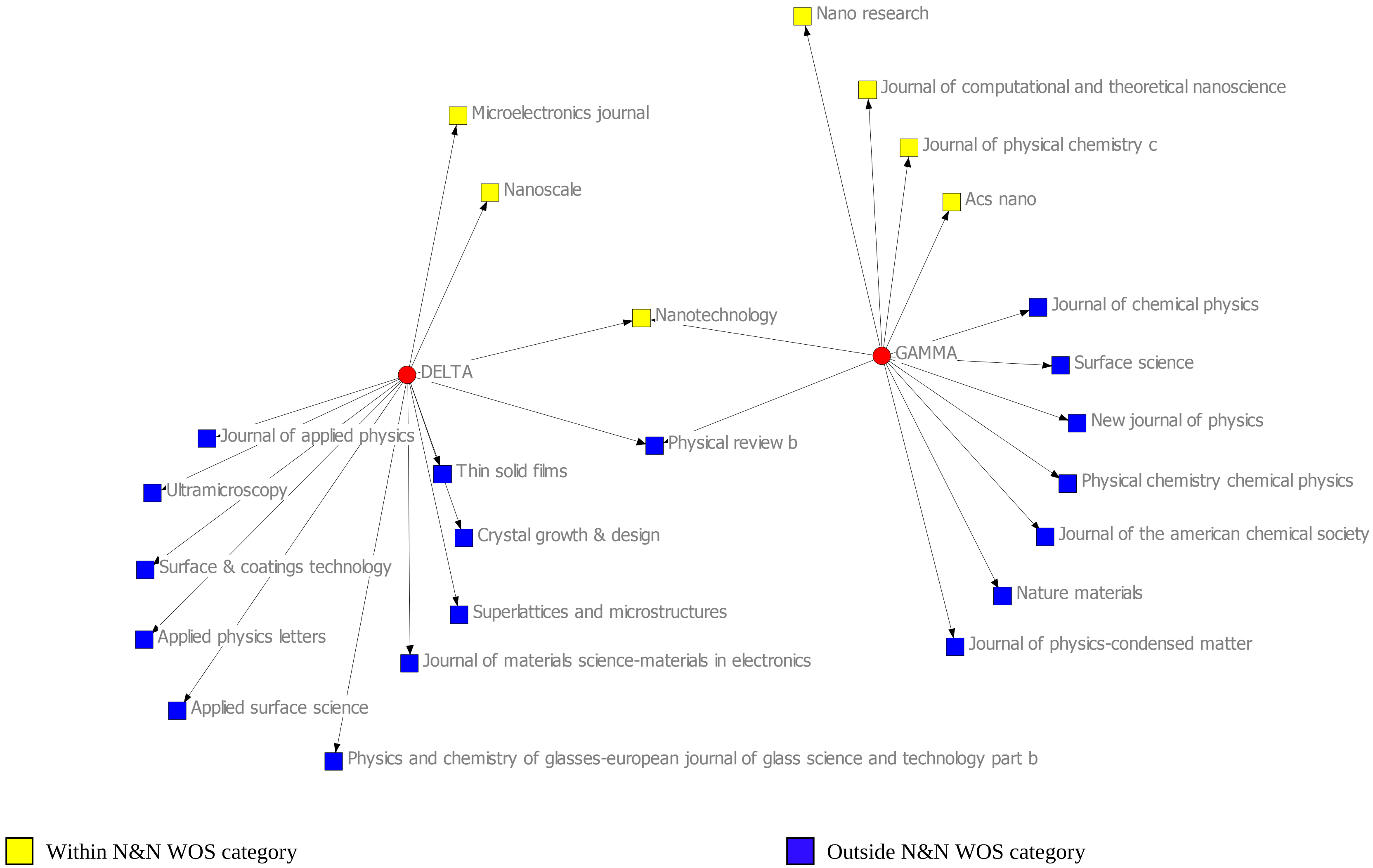
Omega's publications from 1999 to 2011

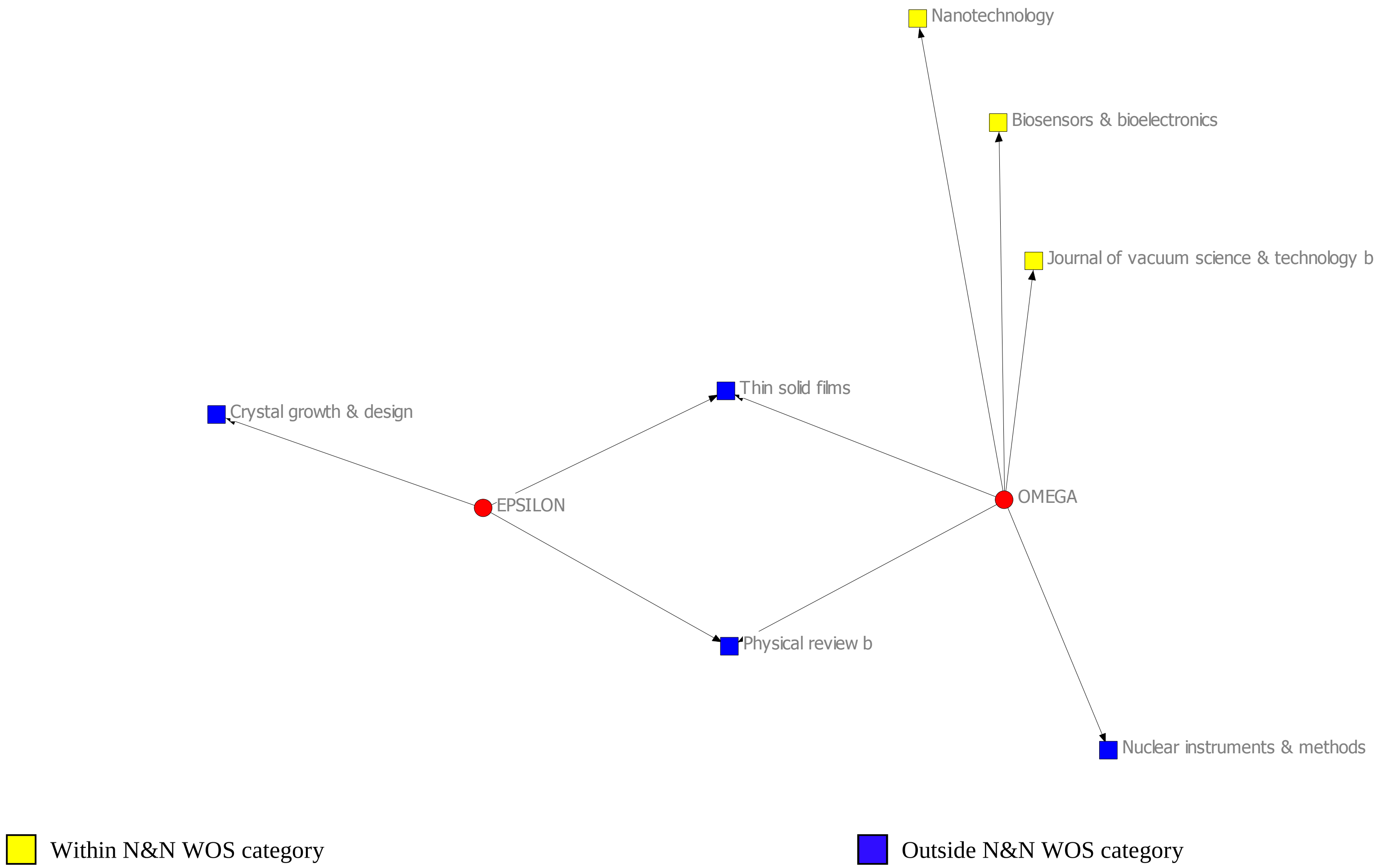
All publications	**Number of publications**	**47**	
	Total of citations	**619**	
	Years of activity of the team leader	13	
	Citations per Publication	13.17	
	Citations per year	47.62	
	Citations per year per publication (mean)	1.91	
	Publications representing 50% of citations	9	
	Publications representing 75% of citations	18	
	Publications representing 80% of citations	20	
	Publications representing 90% of citations	27	
Articles mentioning *nano*	*nano* in the title	2	
	nano in the abstract	3	
	nano in keywords author	1	
	Number of publications	**4**	**8.51% of all publications**
	Citations	**28**	**4.52% of total citations**
	Citations per year per publication (mean)	1.71	(1.91 for all publications)
Articles not mentioning *nano*	**Number of publications**	**43**	**91.49% of all publications**
	Citations	**591**	**95.48% of total citations**
	Citations per year per publication (mean)	1.93	(1.91 for all publications)
WOS N&N category	**Number of publications**	**6**	**12.77% of all publications**
	Citations	**75**	**12.12% of total citations**
	Citations per year per publication (mean)	2.46	(1.91 for all publications)
Not WOS N&N category	**Number of publications**	**41**	**87.23% of all publications**
	Citations	**544**	**87.88% of total citations**
	Citations per year per publication (mean)	1.83	(1.91 for all publications)

APPENDIX F: USE OF THE WORD *NANO* IN PUBLICATIONS



🟨 Within N&N WOS category 🟦 Outside N&N WOS category


Nano research
Journal of computational and theoretical nanoscience
Microelectronics journal
Journal of physical chemistry c
Nanoscale
Acs nano
Journal of chemical physics
Nanotechnology
GAMMA
DELTA
Surface science
Journal of applied physics
New journal of physics
Physical review b
Thin solid films
Physical chemistry chemical physics
Ultramicroscopy
Crystal growth & design
Journal of the american chemical society
Surface & coatings technology
Nature materials
Superlattices and microstructures
Journal of physics-condensed matter
Applied physics letters
Journal of materials science-materials in electronics
Applied surface science
Physics and chemistry of glasses-european journal of glass science and technology part b
Within N&N WOS category
Outside N&N WOS category


Nanotechnology
Biosensors & bioelectronics
Journal of vacuum science & technology b
Thin solid films
Crystal growth & design
EPSILON
OMEGA
Physical review b
Nuclear instruments & methods
Within N&N WOS category
Outside N&N WOS category