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**UNDERSTANDING THE EMERGENCE OF NEW INSTITUTIONAL LOGICS:
A BOUNDARY STORY**

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Abstract: We contribute to the literature of institutional logics by integrating a complementary view which is of composite boundary. We integrate the physical, social, and mental boundaries that encompass both the material and symbolic aspects of institutions in order to study the institutional change of knowledge – ‘Mode 1 vs. ‘Mode 2’. We identified three strategies that describe the extent to which scientists engage in this new area. Embracing is characterised by a commitment to the emerging area of nanoscience and nanotechnology at every level of boundary. While the second strategy – adjusting – describes a partial commitment, the third and last strategy – dissociating – describes a non-engagement to nanoscience and nanotechnology. We then describe that the formation of a new scientific space must be balanced as even the teams that embraced the change do so by relating their work to existing communities. We show that a powerful actor such as funding agencies cannot trigger institutional change if inner actors are not engaged in reconstructing their social and mental boundaries.

INTRODUCTION

Can policy makers trigger the emergence of a new scientific discipline? The question of the relation between science and politics has a long tradition in social science. Weber (1917, 1919/1959) described these domains as two different professions and vocations which must not permeate one another, especially politics into science. However, STS studies show that these two domains are not as separate as Weber wanted them to be. In *Leviathan and the air-pump*, Shapin & Shaffer (1985) show that the construct of scientific fact is not independent from political influences. Latour (1991) pursue this argument by showing that the environment can either enable or hinder the construction of scientific facts and that a science isolated from politics only exists within laboratories as the role of scientists is also to convince people and to find funding (Latour & Woolgar, 1979; Latour, 1987). Although necessary, Jasanoff (1987) describes the demarcation between the two domains as 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 & Kleinmann (2003) argue that scientists must not be involved in policy making but that the boundary which separates the two spheres is contingent to the political context. An instance is given by Oreskes (2003) who shows that a military programme can provide scientists with favourable conditions for basic research. Finally, political decisions can trigger contestations when scientific ethos is put at stake (Slayton, 2007). For a discipline to exist, boundaries must be drawn to preserve scientists' credibility and identity (Burri, 2008). They are necessary to delineate the space within which scientists share similar interest (Bourdieu, 1975) and hold scientific authority (Gieryn, 1995, 1999).

The increasing blurring of boundaries between the two domains, and the involvement of politics in the production of knowledge has been described through various concepts such as national system of innovation (Lundvall, 1988), triple helix (Leydesdorff & Etzkowitz, 1996, 1998), search regimes (Bonaccorsi, 2008), and the most famous one being 'Mode 1' vs. 'Mode 2' production of knowledge (Gibbons et al., 1994; Nowotny, P. Scott, & Gibbons, 2003). While 'Mode 1' defines disciplinary knowledge, homogeneous sites and knowledge production, and problems define by academics, 'Mode 2' describes interdisciplinary knowledge, diverse sites and knowledge production, and knowledge produced within a context of application. Although 'Mode 2' – in line with the other conceptualisations – describes a greater involvement of politics into the scientific activity, the extent to which policy are driving institutional change in the way scientists produce knowledge remains vague (Swan, Bresnen, Robertson, Newell, & Dopson, 2010). Nanoscience and nanotechnology (hereafter N&N) provides a fruitful fieldwork to study these dynamics. Indeed, governments have invested massive funding in this area (Roco, 2005) and even though it is defined as crossing multiple scientific disciplines (Guan & Ma, 2007; Rafols, Zwanenberg, Morgan, Nightingale, & Smith, 2011), the integration of these disciplines is still contested (Bassecoulard, Lelu, & Zitt, 2007; Schummer,

2004). So, the extent to which policy makers trigger institutional change by reconstructing scientific boundaries remains unclear.

Following Swan et al. (2010), we use the concept of institutional logics to study this phenomenon and to clarify the complexity of the relationships between organisational fields and policy (Vermeulen, Büch, & Greenwood, 2007). Thornton & 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 progressively replaced by the ones of the new logic (Friedland & Alford, 1991). However, institutional change does not merely happen with one logic replacing another (Smith-Doerr, 2005) and, moreover, the imbroglia of multiple institutional logics has been overlooked (Lounsbury, 2007; Purdy & Gray, 2009; Smith-Doerr, 2005; Swan et al., 2010).

We are here interested in answering the following research question: to what extent a powerful actor (Pache & Santos, 2010; Ruef & R. W. Scott, 1998), such as funding agencies, can trigger an institutional change by influencing the reconfiguration of the boundaries of science? In other words, we focus on understanding the extent to which the 'Mode 2' logic promoted by policy makers has impacted the production of knowledge and the emergence of a new discipline. As both political and scientific actors were involved during the phase of inception (Granqvist & Laurila, 2011; Grodal, 2010), N&N provides a fruitful context to deepen the understanding of the competition and entanglement between an institutionalised and a new logic (Seo & Creed, 2002). We apply the concept of institutional logics to the area of N&N in Ireland by looking at the impact of the funding initiatives on scientific laboratories. We applied a composite boundary framework (Hernes, 2004a, 2004b) to deepen and to clarify the dynamics of the physical, social, and mental boundaries during the process of institutional change. We explore two communities, policy makers that promote a 'Mode 2' type of research through their funding schemes and scientists that conduct research at the nanoscale. First, we show that the 'Mode 2' logic, although financially attractive, was not mobilised by all scientists and its rejection was in some case a political claim. Second, the 'Mode 2' logic did not have the same impact on each type of boundaries. Indeed, while some laboratories adopted a 'Mode 2' research organisation with multiple scientific disciplines conducting research together, the socialisation and diffusion of the knowledge produced were still disciplinary; in other words, ruled by a 'Mode 1' logics. These results are in line with previous research stating that multiple logics can co-exist within a field and to better understand their dynamics, must be taken into account their physical, social, mental boundaries.

We will describe in the next section the frames of institutional logics and of composite boundaries and how they have been mobilised to explain institutional change. Then, the comparative research design and the qualitative methodology will be detailed. Next, the results showing the entanglement of

multiple types of boundaries under the 'Mode 1' and 'Mode 2' logics will be presented and to finish discussed.

AN INSTITUTIONAL CHANGE AND BOUNDARY PERSPECTIVE READING TO 'MODE 1' VS. 'MODE 2' LOGICS

A composite boundary framework to institutional change

The complexity of the environment in terms 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 & Creed (2002) describe institutional change as the result of a dialectical process during which different logics are competing, and a suited concept to study this phenomenon is this of institutional logics. The latter can be defined 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'* (Thornton & Ocasio, 1999: 804). It is a meta framework (Thornton, Ocasio, & Lounsbury, 2012) that reconciles the determinist view of institutions (DiMaggio & Powell, 1983; J. W. Meyer & Rowan, 1977) with a micro and process approach (Zucker, 1977); in other words, it provides a link between institutions and actions (Friedland & Alford, 1991; Thornton & Ocasio, 2008).

Even though institutional change remains understudied (Lounsbury, 2007; Purdy & Gray, 2009), the literature provides different perspectives of this complex phenomenon. Institutional change is a more or less long process during which logics are competing until the new one succeeds (Thornton & Ocasio, 1999) or fails (Vermeulen et al., 2007) at becoming dominant, or a third logic emerges from an hybridisation of the competing logics (Thornton, Jones, & Krury, 2005). However, it would be oversimplifying to argue that a new logic merely replace or not an old logic (Smith-Doerr, 2005), and that the field reorganises around the logic that becomes dominant (Hoffman, 1999). Indeed, Pache & Santos (2012) show that organisations entering the field can use element from both logic in order to increase their legitimacy. Reay & Hinings (2009) argue that competing logics can coexist through collaborative relationships. Goodrick & Reay (2011) describe how multiple logics can influence individuals in a field and their work. These works show that the imbroglio of logics involves the reconstruction of both the material and symbolic elements which 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, not only the adoption and diffusion of new practices, beliefs, identity, and so on must be studied but also who are the different actors that promote the new logic both within and outside the organisations (Pache & Santos, 2010). Indeed, even though an external shock is likely to trigger an institutional change (Leblebici, Salancik, Copay, & King, 1991), the

adoption of the new logic can find resistance from inner actors (Marquis & Lounsbury, 2007). Building on Oliver's (1991) work, Pache & 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, major funders (Ruef & R. W. 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.

Boundaries between institutional orders are fluid and can be analysed in material 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 the taking into account of both the material and symbolic elements of institutional logics through the focus on physical, social, and mental boundaries. *Physical boundaries* are made of more than just tangible entities, such as infrastructures, but also include who is granted access, rules, distribution of roles and resources, and so forth are also part of what is tied by physical 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). *Social boundaries* refer to what bounds individuals between them, the demarcation between members and non-members have with their organisation and enable the differentiation of one organisation from another. Moreover, it also goes beyond the organisation when it comes to professional norms or work ethics (Hernes, 2004a). As individuals' and organisations' identities are founded by institutional logics (Thornton & Ocasio, 1999), it is an important construct to understand 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 necessary shared meaning without which collective action is not possible (Weick, 1979), and how individuals make sense of their environment (Weick, 1995). At the field level, shared meaning is also essential as it enables a field both to emerge (Grodal, 2007, 2010) and to function (Porac et al., 1989, 1995).

Looking at 'Mode 1' vs. 'Mode 2' institutional change through a boundary perspective

The blurring of boundaries between science, governments, and industry (Gibbons et al., 1994; Leydesdorff & Etzkowitz, 1996, 1998; Lundvall, 1988) has triggered a change in the ways of producing knowledge. 'Mode 1' type production of knowledge describes knowledge that is produced within defined disciplines, embedded in a single paradigm (Kuhn, 1970), and of which research avenues are established by the scientific communities and quality is evaluated by other scientists through the peer-review system. Knowledge is produced by scientists having similar background and science is guided by Merton's (1973) scientific ethos. 'Mode 2' type production radically differs as it characterises an interdisciplinary knowledge which produced within a context of application; in other

word, oriented toward an application. This new way of producing knowledge involves important consequences for research as it makes multiple actors from various institutional orders converge and, therefore, modify their practices, the way they make sense of the results, and their identity. The spread of 'Mode 2' also implies the question of the emergence of new scientific disciplines oriented toward applications contexts with the reconstruction of boundaries around new practices, identity, and mental ties.

< Please insert Table 1 about here >

The blurring of boundaries between science and government has strengthened the steering possibilities of policy makers over scientists. The phenomenon is characterised by a shift in the funding structure from recurrent to project-based funding (Laudel, 2006a, 2006b). Even though resource dependence has to be differentiated from institutionalisation process (Zucker, 1977), regulators and funders are actors that can trigger an institutional change (Pache & Santos, 2010) by promoting a logic over another one. Political control over science is a complex endeavour as policy makers must find and manage a balance between funding areas that can benefit society in terms of social, societal, and economic interest and, providing science with freedom to pursue its own research avenue (Whitley, 1984). The increased involvement of policy makers into research avenues is an element described in the 'Mode 1' vs. 'Mode 2' debate. The transformation of the funding system occurs at three different levels: supranational (for European countries), national, and research councils. At every level, policy makers tend to orient research towards their needs whether be social or economic (Nowotny et al., 2003). Research that can have potential applications will be preferred over basic research. By funding the construction of laboratories, instruments, PhD students, postdoctoral fellows, etc., these powerful actors promote, therefore, a logic that can differ and compete with a more traditional one ('Mode 1') and challenge the different boundaries that guide the production of knowledge. Fostering interdisciplinary and

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 by 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 the peculiar process. Our research question focuses on the extent to which a powerful actors such as funding agencies can trigger an institutional change by influencing the reconfiguration of the physical, social, and mental boundaries of science to form a new scientific discipline?

METHODOLOGY

Fieldwork of nanoscience and nanotechnology

In order to answer our research question, we used a comparative case study research design (Eisenhardt, 1989; Eisenhardt & Graebner, 2007; Yin, 2009) of six research teams to understand how these complex processes evolve over time. By doing so, we focus on how a similar external cause unfold in different institutional contexts (Greenwood & Hinings, 1996; Seo & Creed, 2002). All teams conduct research in the area of N&N, which is the manipulation of particles at the nanoscale – in the range of 1 to 100 nanometres (one billionth of a metre) – in order to understand their properties (Smalley, 2001) and to make new devices (Bhat, 2005). N&N is suited for our study as this area is characterised by an 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 et al., 2007) – that are more or less overlapping (M. Meyer, 2001) and that are mainly driven by physics and chemistry (Bassecoulard et al., 2007).

Research setting and description of the cases

This study was conducted in the Republic of Ireland. This country is suited for this study for two main reasons. First, as this is a rather small and geographically bounded country, actors are easily identifiable. This enabled the authors to have 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 (hereafter STPs) and N&N programmes have enabled the research infrastructures to be developed across the country and the level of funding is now in line with leading countries such as Germany (Forfás, 2011). Moreover, in terms of publication and patent rankings, Ireland has a trajectory of N&N and is among the main European countries that produce over 60 per cent of the publications in N&N in the Science Citation Index (Heinze, 2004). Third, Ireland has largely invested in science from the late 1990s and has shown a more proactive STP since the creation of the main funding agency – Science Foundation Ireland – in 2000. Although STPs and N&N policies are two separated actions undertaken by the government, they are largely intertwined. These two types of funding – directly dedicated to N&N or not – enabled scientists to build up infrastructures but also to offer postdoctoral or PhD scholarships.

The research teams can be described along two main criteria. *First, their belonging to the area of N&N.* Research teams were therefore selected on the bases of the journals they publish in and their classification as ‘nanoscience and nanotechnology’ according to the Thomson Reuters Web of Science (hereafter WOS). *Second, their parent disciplines.* Four out of six activities are related to material science – Gamma, Delta, Epsilon and Omega – and the two others to nanotechnology and biological systems – Alpha and Beta. These areas represent two large sectors, as the former is related to the making of electronic devices, coatings, chips, and so on, and the latter to the study of the toxicity of

nanoparticles, the making of new drugs, new medical devices, and so on. These two sectors are largely fostered in Ireland.

As mentioned earlier, four out of six research teams are involved in material science. Gamma is part of an important research centre dedicated to N&N and tackles the theoretical and computational side of material science by developing a code that aims at predicting 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 ‘pen and paper work’ in order to make theoretical contributions. Delta, Epsilon and Omega present some similarities as they are involved in the experimental side of this discipline. Although all their research has potential application in the semi-conductor industry, they can be differentiated by the techniques they are using and the goal of their research. While Delta is focusing on the growth of semi-conductor materials, Epsilon and Omega study semi-conductor 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 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 – of which human – 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.

< Please insert 2 about here >

Science and technology political context

This section presents the key events in the evolution of N&N in Ireland from the late 1990s onwards. The country was a latecomer into this area, so the first action was the creation of a task force in 2003. This period witnessed the evolution of the definition of N&N, as well as the emergence of different laboratories dedicated to this particular area.

< Please insert Table 3 about here >

The development of science in Ireland is marked by the launch of the first funding cycle of the Programme for Research in Third-Level Institutions by the Higher Education Authority in 1998 (the

funding cycles started in 2000). This round of funding enabled the construction of the centre that hosts Alpha (infrastructure and equipment), as well as the two laboratories where Delta, and Epsilon and Omega conduct their research (see Table 5 below). The Irish government became more proactive about N&N in 2003, with the creation of a task force by the Irish Council for Science, Technology & Innovation (ICSTI). This task force aimed at assessing the capabilities of the country to engage with this area, identifying the different opportunities in terms of technologies and their related potential market, and creating a strategy for the development of N&N. The ICSTI defined nanotechnology as

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 (see Table 5 for the full definition)

The definitions of N&N have evolved over the years from tools and techniques to a science, to be more recently settled as a general purpose technology. The variation in the definitions shows that, during this rather short period of time, policy makers have difficulties in reaching a consensus on the definition of N&N, even in other countries that were more advanced in the area.

< Please insert Table 4 about here >

From a budget viewpoint, under ‘engineering and technology’, a ‘nanotechnology’ category was added in 2006 to the Higher Education Research and Development expenditure (Forfás, 2008: 42). With the creation of this category, we can observe an increase of the expenditure in nanotechnology of 16% between 2006 and 2008 (Forfás, 2010: 40). Then, in 2007, another funding cycle started and this was very beneficial for 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. This consortium fosters the development of N&N related to materials and biological systems by funding equipment, as well as postdoctoral researchers and PhD students. Alpha 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. Beta targeted both European and national sources of funding and started the construction of laboratories *ex nihilo*; European funds were used for personnel, while national funding was used for infrastructure and equipment. Gamma also moved into the area of N&N, not by building a new organisation, but by transferring its activity to a research centre dedicated to nanomaterials and nanodevices. Then, although financial resources were available at both national and European level, neither Delta, Epsilon nor Omega engaged in building new infrastructure or renewing – even renaming – their current facilities.

In 2010, a survey undertaken by the government refined the N&N strategy. The report (Forfás, 2010b) defines three domains on which investment must be focused: advanced materials, sensors (with applications in electronics and health), and nanobiotechnology. In a similar vein, but at a broader scale, a study was undertaken in order to define the areas that should be prioritised in science (Minister for Jobs Enterprise and Innovation, 2012). This took place in a difficult economic context where resources must be optimised. Within this study, N&N is not a priority area, but is considered as a ‘general purpose technology’. Moreover, funding is now no longer dedicated to the construction of new infrastructure, but only to their improvement and renewal. The decrease of funding impacted all the research teams in the same way. Alpha and Gamma reached their objectives in terms of infrastructure while funding was available. However, Beta, which wanted to build a researcher centre that would host multiple principal investigators, was slowed down in its endeavour. The funding cut impacted Delta, Epsilon and Omega in the sense that the size of their teams is limited by the number of pieces of equipment, which are now difficult to replace or even repair in case of a break down.

< Please insert Table 5 about here >

Data collection

The data collection followed two stages. First, the first 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 they obtained their funding, how they sustain the activity, and what funding agencies they submit their applications to. This round of interviews enabled the authors to have a first description of the activity and its environment. The first stage was completed with internal documents, such as funding applications or presentations. Not all research teams were able to provide this type of documentation, due to confidentiality issues with their collaborators. Information required for the study – the description of the project, the reasons why the project has been undertaken, the journals and conferences that are targeted, etc. – was gathered in the interview with the team leader and triangulated with the interview of the postdoctoral researchers or PhD students. Websites were also a good source of information, as a website is a way for the team to advertise its activity and to control its image.

The second stage consisted of interviewing the stakeholders that are related to the activity of interest in our study: team members, policy makers and funding agencies. Their identification was not predetermined and was led by the first stage of data collection. This was essential in order to have a thick description of the team, the different aspects that are encompassed in the activity, and the different stakeholders that are directly or indirectly involved in the activity. Postdoctoral researchers and PhD students were interviewed to develop a better description of the activity and to avoid giving

to much weight to the data collected from the team leaders (Miles & Huberman, 1994). Firstly, team members were interviewed about their career path (both their background and why they chose to come to a laboratory dedicated to N&N or not), their sense of N&N, and their sense of the political and funding environment. CVs were used in order to objectivise their paths and to collect more thorough information regarding the reasons why they moved to the N&N area, as well as their sense of it. CVs were also used to gather information about the journals the interviewees are publishing in, as they are one of the essential supports for a new science to emerge (Frickel & Gross, 2005); journals enable the new knowledge to be diffused and to reach scientists that can potentially be enrolled in the process. We also collected data about the conferences team members are going to. 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).

Secondly, data about the STP environment and funding agencies have been collected in order to build an understanding of both the actions that have been undertaken to develop the N&N area and the context in which they took place. More than two thousand pages of documents were studied to generate a detailed description of how STPs have evolved from the late 1990s onwards, 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 in Forfás, a national agency whose role is mainly to analyse policy and to give advice to the Irish Department of Jobs, Enterprise and Innovation. This was done in order to construct a global frame in which N&N policy is conducted and constructed. In this agency, a delegate to science and technology and a delegate to N&N were interviewed. In order to complete the information about the actions undertaken to foster N&N, the chairman of a group that aims at coordinating N&N actions throughout the country was also interviewed. The dataset was further enriched with documents and interviews with individuals from the agencies cited by the team leaders and members: Science Foundation Ireland; Enterprise Ireland; the Environmental Protection Agency; the Irish Research Council for Science, Engineering & Technology; and the 7th European Framework Programme. For this set of interviews, questions were related to the evolution of N&N in their area, how they promote this line of research, the policy direction the agency is willing to take, their sense of N&N, and the ways they want to fund it.

< Please insert Table 6 about here >

Data collection was rounded out with a second interview of the team leaders in order to gain clarification in the dataset, have more explanation about the team, and ask follow-up questions (Gioia

& Thomas, 1996). This third and last stage was done for two main reasons. Firstly, it enabled us to confirm and to complete the information gathered during the second stage with the team members, and their projects so as to have as accurate a description of the teams as possible. Secondly, questions were asked about what the agencies are providing money for: infrastructure, equipment and scholarships; the ways in which this impacts their research (number of students, publications, research area, etc.); and, finally, in a context of budget reduction and shift from recurrent to project-based funding (Laudel, 2006b), what their strategy is to sustain the activity. This dataset provides a process description of how the events from both the political and scientific contexts unfolded over time. Studying the conditions of emergence through process data (Langley, 1999) is suited as it involves both new and existing actors and, moreover, both the creation of new and the recombination of existing resources.

Data analysis

First step: Identifying the ‘Mode 1’ and ‘Mode 2’ logics

We first built up a description of the evolution of N&N policies in Ireland from the late 1990s onwards. As the country invested massively to develop science over this period of time, we included information related to both 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 that were made to develop science, evaluation and assessment of the research capacity, analysis of the Forfás annual reports from 1998 to 2010, national plans of development – and N&N – changes in the definition of this area, evolution of N&N, Forfás annual reports from 1998 to 2010, N&N-related investments, funding agencies’ documents that are related to N&N. Using process data (Langley, 1999) enabled the authors to understand how the events unfolded over time. The main STP investments were, for instance, the Programmes for Research in Third-Level Institutions (launched in 1998, first funding period: 2000-2003) that 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 PhD students in some of our cases (Alpha and Beta). The content of the annual reports has been essential to understand the wider social context in which teams are evolving.

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 that were gathered to build the infrastructure, funds that are 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 this global frame was written, we described, for all team members, their backgrounds, the description of their projects, to what extent N&N is included in their research, who are the

scientists they are collaborating with, what journals they are targeting and conferences they are going to, and what direction they want to pursue for their career. These different themes allowed the authors to have 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.

Second step: Focusing on the boundary evolution processes

The evolution of the sense that is made of N&N was treated separately regarding the different actors (team leaders and team members) as the sense made by each is likely to be distinct. Indeed, because of their divergent interests, the political and scientific actors involved in this process might not have the same vision of the emergent area. Given their idiosyncrasies – backgrounds of the members, parent disciplines, techniques, journals targeted, etc. – cases were first analysed independently (Eisenhardt, 1989; Miles & Huberman, 1994; Yin, 2009). This gave more room for new themes to emerge. We focused on five themes in particular: (1) how the activity emerged and around what purpose; (2) what were the opportunities that enabled the team to be created (political, funding, and scientific); (3) the extent to which N&N is part of their work and their own identity; (4) the conditions to build a scientific community (outcomes in terms of journal and conference publications); and (5) the converging anticipations that both policy makers and scientists identified for the possible evolution of the field. The five themes were applied to all levels – team leader, postdoctoral researchers, and PhD students – in order to avoid elite bias (Miles & Huberman, 1994).

Third step: Identifying the strategies of co-construction of a field between science and its political environment

During the last stage, we focused on answering the research question: To what extent a powerful actor such as funding agencies can trigger an institutional change by influencing the reconfiguration of the physical, social, and mental boundaries of science to form a new scientific discipline? Hernes (2003, 2004a, 2004b) proposes a composite view of boundaries – mental, social and physical – in order to grasp the complexity of modern organisations. We first identified the material aspects – infrastructures and practices – that tied the organisation together. Then, we focus we focused on both the social and mental aspects. Having the history of each team and its members was fundamental understanding how past experience influences the meaning of N&N and also the identity construction. Although organisations are ‘oriented toward the future’ (Schultz & Hernes, 2012), their identity is the result of past processes and is constrained by the present environment (Emirbayer & Mische, 1998). We then compared the cases to build more abstract constructs and to understand to what extent the different research teams moved to the N&N area and the extent to which they formed a new scientific discipline. Through this analysis we have been able to describe the extent to which policy makers

impact the scientific logics (Thornton & Ocasio, 2005; Thornton et al., 2012) and make scientists move from an extant to build a new one.

INNER DYNAMICS – ORGANISATIONAL RESPONSES TO N&N POLICY: EMBRACING, ADJUSTING AND DISSOCIATING

The first section focuses on the organisational responses (Pache & Santos, 2010) that occurred under the fostering of the ‘Mode 2’ logic. We describe the extent to which this new logic has impacted the physical structures, equipment, scholarships, etc.

Embracing

This first dynamics of change describes teams that integrate the change at all levels of boundaries. This change has possible because of inner respondents within organisations (Pache & Santos, 2010). Research teams in this emerging area of science faced different choices regarding the change that was occurring in their environment. Our data suggests that scientists who embraced the change integrated N&N at every level of their boundaries: mental, social and physical. This deep organisational change was characterised by either the creation of a new entity *ex nihilo* or the recombination of existing resources. By doing so, scientists delineated a new organisation that better fits the environment and was made visible for both policy makers and the scientific community. This was particularly the case for Alpha and Beta. These teams mobilised both national and European funding to build a new organisation. However, the change did not only occur at the physical level of the organisations, but could also be seen in the way in which the teams perceived themselves in the production of their outcomes.

N&N is characterised by a lack of standards in terms defining the size of nanoparticles, how to regulate them, their potential harmfulness, etc.; in other words, what can be considered as being N&N and what cannot. Moreover, it cannot be reduced to a single technology as it ranges from microscopy instruments – such as the atomic force microscope or tunnelling electron microscope – to lithography techniques via deposition techniques to form coatings, etc. These technological evolutions represented more drastic changes in some area of science compared to others. For instance, understanding and using the properties of nanoparticles with techniques that come from physics and chemistry to interact with biological systems is an area that was overlooked in science; the limitations being the ability to see and manipulate the particles at that scale. Thus, the possibilities opened by these techniques enabled different scientific disciplines to converge. For Alpha and Beta, these loci of convergence – characterised by multidisciplinary and a lack of established protocols – were seen as new areas to be explored. Alpha was built from two existing groups, of which one has since disappeared and the other one renamed. The aim of this change was to gather 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: scientists on the characterisation of nanoparticles, on the one hand, and scientists studying the toxicity of the nanoparticles, on the other. Although these two branches were meant to be distinct in the original proposal, both postdoctoral researchers and PhD students happened to extend their research to both areas. Beta was built on 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 the acquiring of the grant and the opening of the building, the team was hosted in the department of molecular biology.

Even though both teams' leaders have their backgrounds respectively in physics and chemistry, they describe N&N as something more than a technological evolution or a relabeling of already existing areas, for example:

I really felt it was a bandwagon until I really started to think, I don't know even in the past five years, ten 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)

Moreover, by having set up new physical boundaries, a common sense of N&N could be co-constructed and, therefore, shared among the members of the organisation. This sense of nano as a new area of science is even stronger among PhD students as they started their scientific life directly in this area and, thus, their professional identity is constructed to fit their work (Pratt, Rockmann, & Kaufmann, 2006):

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 developments of semiconductors and stuff, that's all physics based whereas nano exists in all of the three main disciplines. And if you were a nanoscientist you have to have solid grounding in all three, you know. If you think of an application of nanotechnology, you have to have a decent grounding in them all. It doesn't really fall under any one. It's unique in that sense. (Alpha 3.1, PhD student)

In a similar vein, Beta's members made sense of N&N as an emerging area, with all the related opportunities in terms of publications, but also how society can benefit from this new research area:

We are sort of coming at the start of it or with when it is emerging and it is becoming big. So, I think it is very good to be here now in order to – how can I say to find ourselves placed in this market in the future, for the future. (Beta 2.2, postdoctoral researcher)

Making sense of N&N as an emerging area of science is influenced by the way in which social boundaries are drawn and constructed (Weick, 1995). Organisational identity is what ties an organisation together and makes it different from another one (Hernes, 2004a). The physical boundaries that have been set up with financial support from national and European funding agencies enabled the scientists with diverse backgrounds to forge an organisational identity. For both Alpha and Beta, N&N and multidisciplinary are two strong characteristics of their organisational identity. For

instance, as Alpha has been built within a research centre through the recombination of capabilities, historical linkages and collaborations exist between the scientists that formed Alpha and the biology group that existed before Alpha's creation. Even though these two teams are working on biological systems, the creation of the laboratory enables Alpha's members to locate them within the centre:

There is a difference because I don't know much about radiation. They don't know much about nanoparticles. So we are specialised in different ways, but working in the same lab using the same instruments and probably using some common techniques or assays. So there is lots of thing that are common, but the approach is different. In the nano thing the approach is a little different. In radiation biology, the approach is different. (Alpha 3.3, PhD student)

In a similar vein, Beta was created before the construction of the research infrastructure. Beta was hosted in another department in order to use its facilities. Even though this was a centre dedicated to biology, the creation of Beta as an entity with a name and purpose enabled Beta's members to differentiate them from the biology centre's members:

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 construct an identity that would define them and separate them from scientists in other disciplines, especially those who started their studies in this new area. In these two 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 infrastructure with equipment where scientists can conduct their research. Moreover, although organisational identity delineates organisations from one another, it also goes beyond the organisation's boundaries regarding the field these organisations in which they are embedded. A field can be defined as organisations that provide similar products or services (R. W. Scott, 2008). In our study, laboratories produce scientific outcomes that are published in the journals that are read by the community they want to interact with. Policy makers facilitated the construction of research laboratories and centres dedicated to N&N and for which N&N is central to their self-perception.

Adjusting

This second strategy is characterised by a partial engagement with N&N. Not all types of boundaries were impacted by the change. We observed for one case, Gamma, a decoupling between the organisational structure and the social and mental elements. Indeed, although the structure promotes interdisciplinary research, scientists a similar background and hardly identify themselves to the N&N community. In the other case, Delta, they identify themselves to the N&N community, the structure and the mental dimensions are still guided by a 'Mode 1' logic. As some sub-disciplines of science, such as material science or computational science, were conducting research at the nanoscale before N&N took off, N&N did not impact these sub-disciplines to the same extent. In this case, our data

show that some teams did not entirely commit to the N&N area – regarding their mental, social and physical boundaries – despite the financial and scientific opportunity. We found two different ways to adjust to the N&N emerging area: on the one hand, a change regarding the physical boundaries of the organisation but with almost no sense of belonging to the area and on the other hand, a mitigated sense of belonging but not to the extent of creating a new entity. Two research teams are representative of this strategy: Gamma and Delta. In relation to N&N, Gamma joined a research centre dedicated to nanomaterials and nanodevices, while Delta did not engage in creating a new entity or even renaming the existing one. For these teams, the physical boundaries were therefore weaker than for those pursuing an embracing strategy. Moreover, even though Delta's members argue that their work can be categorised as N&N, this does not constitute the core characteristic of their identity. Rather, N&N is seen as a way to explore the quantum properties of the particles or as a way to improve their research and therefore to publish.

Gamma's activity is categorised in the sub-discipline of computational physics. Using super computers, they simulate how one or a couple of atoms behave under certain conditions. Even though this team is hosted by a research centre that is dedicated to nanomaterial and nanodevices, N&N is more seen as a trend that consumed their discipline. Indeed, as dealing with atoms and their properties is the purpose of their discipline, their work is deeply embedded in theoretical physics and computing. Even though they acknowledge that N&N has a lot of potential in terms of applications by bringing disciplines together, Gamma scientists saw the multidisciplinary that was core to Alpha and Beta making N&N too broad to be scientifically relevant. Moreover, the evolution of computational science is more linked to improvements of computers and their capacity to treat information than to technological advances in microscopy or lithography. So, by not being tied by the experimental side of science and the cost of instruments, Gamma can adapt their research and find applications for their work in more favourable trends if this improves the sustainability of the team:

For the [University] grant we specifically added a part on solar energy in our proposal because we knew that they were interested in solar energy. Because in Saudi Arabia they have the oil but the oil will run out but Saudi Arabia has a lot of sun and a very strong sun and so, it might be a very good place to produce solar energy and then sell that, you know. (Gamma 2.6, postdoctoral researcher)

Gamma's social boundary is distinct thanks to these two aspects of material science and, more specifically, magnetism and computing, which enables them to separate their activity from those of the experimental physics team. Moreover, N&N is peripheral and fluid and, thus, can be adapted if a more relevant trend is found for the team:

We're now keeping an eye on energy because of course there's a big emerging field but actually... But also energy, I mean in the sense of we're still talking about nano so it's actually kind of nanoscience that's related to energy application. So it's not actually a 180 degree turn. (Gamma 1.1, team leader)

Delta's team leader emphasises the incremental aspect of N&N in his research. Working on sensors, N&N is a way to produce better sensors or to grow better materials. N&N is not an end of their research. In this way, the lack of standards makes N&N more a trend and a buzzword than a technology that deeply impacted their discipline. Moreover, in a similar vein as Gamma, the research conducted by Delta can be located in the discipline of material science. So, this embeddedness in an established discipline, the lack of standards of N&N, and the multidisciplinary that characterised this area made difficult the taking into account of N&N into Delta's identity. However, even though Delta's leader never felt the need either to create a new entity or to rename his team in order to include 'nano' in the name for instance, the size of the materials they are working on is at the nanoscale and, therefore, they use techniques related to this area.

I still consider myself to be working on semi-conductor 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)

For Gamma and Delta, N&N is not seen as the main characteristic of their identity, but as a peripheral feature that helps to distinguish them from others and to adapt their activity to the changes in the environment.

Dissociating

This third and last strategy is characterised by an absence of engagement at every level of boundary. Inner scientists did not respond to the 'Mode 2' logic. Even though the N&N trend is known among the organisation's members, it is largely ignored and characterised as external to the scientific community, and, therefore, not scientifically relevant. This strategy is well illustrated by Epsilon and Omega, two teams that did not engage in creating or renaming an organisation, but also that barely used the word nano in their publications. Although they recognised the financial opportunity that N&N afforded in Ireland, their research and identity remain embedded in their established community.

For Omega and Epsilon, N&N is considered a trend or a fancy word. Omega sees N&N as a trend, although the research they conduct is 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 in it. 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] have their own XPS source here and they are working on a more kind of barrier layers for computer chip. No, it's completely different. We sometimes use the same equipment, we sometimes share power sources and bits and bobs because we are the surface science nano technology department. (Omega 3.1, PhD student)

Epsilon's members – and especially Epsilon's team leader – have a more drastic view of N&N and perceive it as a fashion trend that does not define the area in which they do their 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 material science. This vision is shared by the postdoctoral researcher and PhD students, who see themselves as working in an area that has no direct applications:

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 semi-conductor 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 that they use to differentiate themselves from other teams or disciplines.

< Please insert Table 7 about here >

OUTER DYNAMICS: CONSTRUCTION OF A LOOSE SCIENTIFIC SPACE OF N&N

This section aims at deepening the understanding of the creation of a common space once science had the necessary financial support to conduct research at the nanoscale and how the central or peripheral characteristic is used towards the established science disciplines. That is, how the interdisciplinary aspect of the 'Mode 2' logic changed the production of knowledge. Moreover, we deepened the extent to which it can be observed in their outcomes – the journals they target and the conferences they go to. N&N is not only a political construct as it is supported by the scientific community – some journals are dedicated to N&N and some established ones have extended their scope to this area – which gives researchers the possibility to be both funded for their research and to be able publish it. We show that the convergence towards a homogeneous area of science is rather limited and that the pattern of interactions differ depending the strategy adopted by the scientists. Indeed, only a few journals are common to the different disciplines and the ambiguity surrounding N&N make the convergence even more difficult. As the structure of science remains very stable, we witness more the renewing of extant disciplines than the emergence of a new one. In terms of journal publications, teams who embrace N&N find themselves peripheral to both the community they are coming from and the community they want to reach. They interestingly strongly identify themselves as N&N and use it in order to justify their entry into the new discipline. Those who adjust to and dissociate from N&N stayed in their discipline and publish into the journals from their respective discipline that extended their scope to N&N.

Scientific production

We here focus on how the research teams that embraced N&N interact with the scientific community through journal publications. We looked at both journals that are classified as ‘nanoscience and nanotechnology’ by Thomson Reuters Web of Science (WOS) and the use of the word *nano* in the title, abstract and keyword of the articles in order to differentiate a classification made by an external institutional actor – Thomson Reuters – and a voluntary engagement to N&N. If we look at the patterns of publications of each team’s founder, we can see a change in their use of their publications. Since 2008, Alpha’s foundation year, 25 articles or 53.19% of the team’s total publications mention the word nano and count for 284 or 58.20% of its total citations. If we include 2007 – year during which projects with nanoparticles were conducted, but Alpha was not officially created – the publications mentioning the word nano increase to 29 articles and count for 624 citations (66.1% of the total citations). This partial commitment to N&N is explained by the fact that Alpha’s leader is also manager of the research centre and a part of his publications includes other domains of research. However, even though more than a half of Alpha’s publications mentioned the word nano, only 8 articles (17 % of all publications) are published in journals classified as ‘nanoscience and nanotechnology’ by the WOS.

Change is even more drastic for Beta’s team leader, as he created Beta *ex nihilo* and his time is fully dedicated to this organisation. Since 2007, Beta’s foundation year, 40 articles (88.89% of publications) mentioned the word nano, which represents 1,838 citations (98.87% of total of citations). However, among these 40 articles, only 17 (37.78%) are classified as ‘nanoscience and nanotechnology’ by the WOS. Even though Alpha and Beta’s members make sense of N&N as an emerging discipline and identify themselves as such, their specialty on N&N spreads beyond the journals classified as ‘nanoscience and nanotechnology’ by the WOS. Moreover, although they evolve in a similar area of research, they only have four journals in common among the 35 they have published in since their inception, and two of these four are journals that were targeted with common publications. Alpha and Beta’s publications span multiple disciplines: physics, chemistry and biology. This reflects the multiplicity of backgrounds that constitute the team and the techniques that are involved in doing their research, but also the lack of homogeneity within this emerging area.

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 (25.23% of total publications) have 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 having joined the research centre dedicated to nanomaterial and nanodevices. Still, about a quarter of the team’s publications contained the word nano and even less are falling into the WOS ‘nanoscience and nanotechnology’ category. 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 sense that is made of N&N as a trend that is too broad to be scientifically relevant to their area of research, as well as their self-perception as computational scientists, than belonging to a new breed of scientists.

The picture is different for Delta, as they did not belong to a physical organisation that claims its membership of the N&N area. Indeed, Delta's team leader started to use the word nano from 2004 and in an increasing manner until 2011 (end of the data collection period). Even though Delta's team leader claims to have switched his attention to N&N in the very late 1990s, the change in his publications can really be seen from 2004, when Ireland started to become more proactive in this area. In a similar vein as Gamma – and to a certain extent Alpha and Beta – 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 nanoscience and nanotechnology. For both teams, the majority of their research is published outside the WOS 'nanoscience and nanotechnology' category. However, they use the word nano either in the title, abstract or keywords of their articles in order to contribute to the discipline they are embedded in.

Overall, 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 'nanoscience and nanotechnology' category. Since the centre was created in 1999, four articles (8.51% of total publications) contain the word nano and six are classified as 'nanoscience and nanotechnology'. Among the articles that mention the word nano, none follow a specific trend as the articles have been 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.

Epsilon follows the same trend. Since he started to publish in 1980, Epsilon's team leader has published only five articles that mention the word nano. Since the centre's creation in 1999, Epsilon have published three articles mentioning the word nano. However, 11 of the team's publications fall into the WOS 'nanoscience and nanotechnology'.

Conferences and scientific community

Conferences are another important aspect of science, as they enable scientists to present their work, share ideas and build collaborations and can be a locus for emergence (Lampel & Meyer, 2008). Conferences are important places as this is where norms, practices, beliefs, etc. are shared, discussed challenged. They are, therefore, an important regulatory mechanism (DiMaggio & Powell, 1983; Ruef & R. W. Scott, 1998). For the teams for which the activity spans over multiple established disciplines, such as Alpha and Beta, conferences that would encompass the whole activity 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 scientists are working on – in other words, what is core to their research – will drive the conferences they target. The learning-side of conferences is very important for PhD students, as they have to learn and meet the experts in their techniques. Multidisciplinarity makes the expertise difficult to possess within the boundaries of the organisation. For Alpha, for instance, the organisation's members attend conferences according to their work.

[Alpha 3.5]'s work is being presented at SETAC, 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 saying, 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)

Then, the dual aspect between N&N and the inheritance from established disciplines in terms of techniques makes the emergence of a common ground difficult. Although multidisciplinary conferences, where diverse actors will meet in order to deal with the application or regulation aspects of N&N are places for scientists to go, the strong scientific side of their work would not be treated during these events. As N&N does not have its own standards, scientists must learn from knowledge existing in established disciplines. For instance, Beta's members will tend to attend conferences that both deal with the N&N aspect of their work and also those that deal with the core scientific knowledge of their work:

More recently, they are coming more bio-nano general people studying regardless of drug delivery, regardless toxicology, people that are just as we are trying to do understanding the mechanisms and this kind of things. So there are conferences that are with this focus. And then I am going to conferences that is said they are biology conferences, nothing to do with nanoparticles. (Beta 2.3, postdoctoral researcher)

The very broad spectrum of N&N makes the emergence of common social events rather difficult considering that the specificity of each research project is tied to a type of knowledge that is embedded in an established discipline. As scientific impact would be harder to achieve in very broad conferences, given that peers are not necessarily attending this event, embracing N&N also constitutes a medium to make an impact on an already existing discipline. This is relevant considering the scientific heritage within which organisations such as Alpha and Beta are embedded and the novelty that is brought by their focus on N&N. Even if both of these teams have members that attend broad N&N conferences, they also try to impact existing communities in order to establish their scientific relevance:

For the kind of things that I am studying, you know, I'm going to uptake mechanisms conferences because we are studying those things. They don't know anything about nanoparticles. We need to present them what we are doing about their topic with the nanoparticles, and where they have to

learn how they do the things. So those are conferences for us to learn and present. (Beta 2.3, postdoctoral researcher)

We saw that the teams that embraced N&N engage in a change regarding all types of boundaries. They develop a common meaning of N&N and it is incorporated into the social boundary that ties the organisation together. Both the mental and social boundaries are strong elements that show that these teams are willing to make a distinction between their activity and the established disciplines they inherit. The construction of physical boundaries enabled them to focus their research on a certain aspect of N&N. At the community level – field level – N&N is mainly used as a feature to distinguish the research from existing communities.

For Gamma and Delta, broad N&N conferences – although interesting to know what is happening in the N&N area in terms of applications – are not relevant enough in order to make progress on the scientific side of their work. Both of these teams evolve in sub-disciplines of science that have been encompassed by the N&N area, but that find their roots in established communities. Indeed, even though computational science is a rather new discipline compared to material science, their respective births are prior to 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. In both cases – and in a similar way to Alpha and Gamma – scientists go to conferences that are deeply related to their work. N&N conferences are considered too broad and, thus, collaborations are difficult to establish:

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, but 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 of these cases, given the monodisciplinarity and embeddedness of their research in an established discipline, N&N conferences remain too general to be relevant. Even though generalist conferences structure their communities, these events are traditionally material science events, such as the American Physical Society (APS) 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 to establish collaborations. In a similar vein, as N&N is a peripheral characteristic of their identity, scientists can go to conference sub-themes that would be dedicated to N&N. The latter is more seen as a specialisation than 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 used the word nano in their publications. So, both teams adjust to environmental pressures in different and

partial ways. Gamma modified the physical boundaries of their organisation, whereas Delta modified their way to engage with the scientific community.

In a similar way to their publications, Omega and Epsilon do not target broad conferences that are dedicated to N&N. The generalist conferences they are targeting are dedicated to surface science and not N&N. We saw that both Epsilon and Omega did not engage in the creation of a new entity or in renaming their organisation. Although this is similar to Delta, they, however, see N&N as a buzzword and a trend, and even perceive themselves as being outside of this vision. At all levels of boundaries, they did not engage in this area of N&N.

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DISCUSSION

We used a composite boundary framework within the institutional logics perspective in order to describe the impact of a powerful actor – science and technology policy – on the reconstruction of the physical, social, and mental boundaries around a new scientific discipline. We saw that although STPs enabled some changes among incumbent organisations, the adoption of the ‘Mode 2’ logic has been only partial. By applying a composite boundary framework (Hernes, 2004a, 2004b), we showed that funding agencies impact first the physical boundaries of organisations while social and mental boundaries are still tied to the scientific communities. Using a composite frame enabled to shed light to dynamics that would have remained hidden otherwise (Beckert, 2010). Even though inner actors have the capabilities, they did not necessarily move to the new and financially attractive area. This calls for discussion to improve our understanding of institutional change. 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 get to a finer-grained level of analysis in order to deepen the dynamics during an institutional change. The interplay between the three types of boundaries shows that constraining organisations to adopt a new logic via funding will mostly push organisations to adopt the physical structure but not necessary the symbolic elements (Friedland & Alford, 1991; Thornton et al., 2012; Thornton & Ocasio, 2008) that are necessary for a new logic to emerge. Indeed, the mental ties are essential for a community to function (Porac, Thomas, & Baden-Fuller, 2011; Porac, Thomas, Wilson, Paton, & Kanfer, 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 & Laurila's (2011) study which shows that the ideas promoted by the futurist and science fiction community permeated the scientific sphere and enabled scientists to reframe their own concepts. Moreover, in the primary phase of institutional change where multiple actors are involved and

competing to promote their own logic, it is useful to identify on what element the both the new and old logic crystallise. In our case, while organisations' physical boundaries were partially ruled by a 'Mode 2' logic, social and mental boundaries were still guided by a 'Mode 1' logic. Moreover, mental elements provide a framework to construct the social and regulative element (Ruef & R. W. Scott, 1998). As the policy makers' intervention failed at reconstructing the mental boundaries of scientists, the way scientists make sense of 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 & Hinings (2009) show that competing logic can co-exist through the development of collaborative relationships and that the competition between logics is not necessarily solved with a logic becoming dominant (Hoffman, 1999). Moreover, multiple logics can influence the practices and identity of both individuals and organisations (Battilana & Dorado, 2010; Goodrick & Reay, 2011). Describing multiple logics might help to understand how a new logic succeeds or fails at becoming dominant. This is relevant for professional fields that face an institutional logic shift (Lounsbury, 2007; Reay & Hinings, 2005; Thornton et al., 2005) or 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 not likely 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 the 'Mode 2' is spreading and becoming dominant, the disappearance of the 'Mode 1' logic is contested. Indeed, the two logics have always been there but the rise of the 'Mode 2' is explained more by a shift of dominance between the two logics rather than the rise of a new logic. This is in line with Reay & Hinings (2005) who argue that '*when a dominant institutional logic exists, it is because other logics are subordinate*' (p.352). So, considering the physical, social, and mental element of an institutional logic, even at the field level an institutional change can be witnessed, it might not be the case at the micro level (Stål, 2011).

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Table 1: 'Mode 1' vs. 'Mode 2' logics (source: Swan et al., 2010: 1313)

'Mode 1' knowledge production	'Mode 2' knowledge production
Problems defined by academics and professional communities	Knowledge produced in context of application
Disciplinary knowledge	Transdisciplinary knowledge
Homogeneous sites/types of knowledge production	Diverse sites/types of knowledge production
Research as objective investigation	Research as reflexive/ dialogical
Quality control by 'invisible colleges'	New forms of quality control and required with social accountability

Table 2: Description of the research teams

	ALPHA	BETA	GAMMA	DELTA	EPSILON	OMEGA	TOTAL
University	University 1	University 2	University 3	University 4			
Areas of the activity	Nanotoxicology, pharmacology	Nanobiology, nanosafety, nanotoxicology	Computational physics	Material science	Material science	Material science	
Purpose of the research team	Understanding the toxicity and the behaviours of nanoparticles within human, mammalian, fish cells and algae by using spectroscopy techniques	Understanding how nanoparticles behave and interact with biological systems in order to use their properties for medical purpose	Understanding the electromagnetic properties of certain nanoparticles through computational simulation to both improve theory and computational tools	Understanding the growth of semiconductors and nanostructures by using multiple characterisation techniques	Understanding the chemical interactions on semiconductors surfaces in order to improve their electrical properties	Understanding the 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)	
Professor	1*	1*	1*		1*		4
Lecturer	1*			1*		1*	3
Doctor		1*					
Postdocs	2	4	6		1	1	14
Ph.D. students	6	1	3	3	2	3	18
Individuals	10	7	10	4	4	5	40

* Team leader

Table 3: Key dates in the development of N&N in Ireland

Year	Relevant events in nanoscience and nanotechnology policy
2000	<ul style="list-style-type: none"> - 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 Programme for Research in Third-Level Institutions cycle 1 (year of reward: 1999). This cycle has funded the centre that hosts Alpha as well as the two laboratories where, respectively, Delta, and Epsilon and Omega are conducted their research.
2001	<ul style="list-style-type: none"> - First time ‘nano’ (‘nano-materials’) is mentioned in an annual report (2000 Forfás annual report, published in 2001) as part of the research areas fostered by the Sixth European Framework Programme.
2002	<ul style="list-style-type: none"> - Start of the Sixth European Framework Programme with the third priority area of ‘Nanotechnology and nanosciences, knowledge-based multifunctional materials and new production processes and devices’ (NMP). Nanoscience and nanotechnology are funded at the European level in a more structured way.
2003	<ul style="list-style-type: none"> - A task force is created by the Irish Council for Science, Technology and Innovation to (1) to establish the nanotechnology capacities already present in the country, (2) to identify the opportunities and (3) to create a strategy for the development of nanotechnology.
2004	<ul style="list-style-type: none"> - The Irish Council for Science, Technology and Innovation published its report where it establishes a roadmap and the different opportunity sectors such as information and communication technology, healthcare, agriculture and food, polymers and plastic, and construction.
2006	<ul style="list-style-type: none"> - Creation of a sub-category ‘nanotechnology’ under ‘engineering and technology’ within the Higher Education Research and Development expenditure budget. - A technology assessment has been made by Forfás in order to identify the investments and policy decisions that should be undertaken for the development of N&N.
2007	<ul style="list-style-type: none"> - Start of the funding period of the Programme for Research in Third-Level Institutions 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	<ul style="list-style-type: none"> - Publication of an important study ‘Ireland’s Nanotechnology Commercialisation Framework 2010-2014’ that assesses the nanotechnology research capabilities in terms of both publications and patents. This study aims at identifying the market within which Ireland could be the most successful. This study led to the creation of a coordination group in charge of developing nanotechnology industry and assessing the achievement of the previously established goals.
2012	<ul style="list-style-type: none"> - Considering the slowdown in the economy and the budget reduction, Ireland has undertaken 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.

Table 4: Evolution of the definitions of nanoscience and nanotechnology

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. <i>Irish Council for Science, Technology and Innovation Statement on Nanotechnology</i> : p.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. <i>Annual report 2005</i> : p.41).
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. <i>Annual report 2006</i> : p.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 foreign direct investment (FDI) in areas such as medical devices and electronics (Forfás. 2010. <i>Annual report 2009</i> : p.46). ‘Purposeful engineering of matter at scales of less than 100 nanometres (nm) to achieve size-dependent properties and functions’ (Forfás. 2010. <i>Nanotechnology Commercialisation Framework 2010-2012</i> : p.19).
2011	‘Nanotechnology is a key enabling technology across multiple markets and sectors...’ (Forfás. 2011. <i>Annual report 2010</i> : p.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’ (Research Prioritisation Steering Group. 2012. <i>Report of the Research Prioritisation Steering Group</i> : p.36).

Table 5: Funding agencies and research teams

Type of funding	ALPHA	BETA	GAMMA	DELTA	EPSILON	OMEGA
INSPIRE*	equipment and scientists	equipment and scientists				
PRTL cycle 1	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	scientists		

*INSPIRE: Integrated NanoScience Platform for IREland is a consortium that groups 8 universities from Ireland and 2 from Northern Ireland. It has been funded under the PRTL cycle 4 (Higher Education Authority) in order to enhance the collaboration between partners in nanoscience and nanotechnology.

**EPA: Environment Protection Agency

***IRCSET: Irish Research Council for Science, Engineering & Technology. It awards students from their marks and the project.

Table 6: Description of the political environment

	Forfás	Science Foundation Ireland	Enterprise Ireland	Environment and Protection Agency	Irish Research Council for Science, Engineering & Technology	7th European Framework Programme
Description	Advice to the Department of Jobs, Enterprise and Innovation. This agency	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. They fund applied research and projects that have a possible industrial applications.	Agency that funds projects that are directly related the protection of the environment. Its role is also to provide rules to polluting activities and to monitor the environment.	Its role is to support research at the master, doctoral and postdoctoral level. Funding is provided based on the relevance of project and the student who will be carry on the project.	Framework Programmes are one the main European funding instrument. 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.

Table 7: Embracing, adjusting and dissociating strategies

	EMBRACING	ADJUSTING	DISSOCIATING
Definition	<p>Every level of boundary (physical, social and mental) is committed to the new area</p> <p>The characteristic of the new area are perceived as a radical change compare the fields it inherits from</p> <p>The characteristics of the emerging area become core characteristics of the organisational identity</p>	<p>The organisation do not commit entirely to the new area and some levels of boundary remain embedded in established fields</p> <p>The characteristics of the new area are not considered as a relabelling or an incremental change of the current activity</p> <p>The characteristics of the emerging area are peripheral characteristics of the organisational identity</p>	<p>No type of boundary is committed to the new area. They all remain embedded in their established fields</p> <p>The current activity is perceived as outside of the emerging area and thus the characteristics are integrated in the organisational identity</p>
Mental and social boundary	<p>Integration of the characteristics of the emerging area to the organisation's identity</p> <p>Claiming membership to the emerging area</p> <p>Sense of radical change is comparison to the disciplines the organisation inherits from</p>	<p>N&N is a peripheral characteristic of the organisational identity and is used to demarcate the organisation from other more traditional organisations</p>	<p>N&N is perceive as external to their research area is not used in any ways as part of the organisational identity</p>
Physical boundary	<p>Creation of new physical boundaries in order to delineate the emerging activity and to better fit the environment. Rules are co-constructed within the news area and tend to differentiate the activity from established fields</p>	<p>New physical boundaries are not essential to adjust to the environment</p> <p>Rules are embedded in existing fields</p>	<p>No physical boundaries are created nor existing organisations relabelled</p> <p>Rules are based on the disciplines they are embedded in</p>
Interaction with the environment	<p>Interactions are made both the emerging area and the fields it inherits from. N&N is used as means to create a new mental community or as a vector to impact an already existing community</p>	<p>N&N is used in the existing discipline both as scientifically relevant and to follow the trend. Change in the wording rather than in the pattern of publications</p>	<p>Patterns of publications have not changed and the word nano is neither used to create a new discipline nor to impact an existing one</p>
Instances	<p>A new organisation is created in order to dissociate the activity from established research. N&N and the characteristics that are attached to it are integrated in the identity. N&N is seen as a radical change and different from the type of research that is done in established disciplines.</p> <p>Use of the emergent area in order to impact existing disciplines or to create a new research specialty. Generalist journals are targeted</p>	<p>An organisation can change by integrating an entity dedicated to the emergent area. N&N is seen as too broad to be scientifically relevant or only as an incremental improvement.</p> <p>Renaming the research in order to fit the area</p>	<p>No organisation has been created or even renamed. N&N is mainly seen as a fashion trend. The emergent is out of their discipline. The word nano is barely, even not, used in the publications</p>

Table 8: Mobilisation of the 'Mode 1' and 'Mode 2' logic according to the type of boundary

	Alpha	Beta	Gamma	Epsilon	Delta	Omega
Physical boundary	Mode 2	Mode 2	Mode 2	Mode 1	Mode 1	Mode 1
Social boundary	Mode 2	Mode 2	Mode 1	Mode 1	Mode 2	Mode 1
Mental boundary	Mode 1/Mode 2	Mode 1/Mode 2	Mode 1	Mode 1	Mode 1	Mode 1