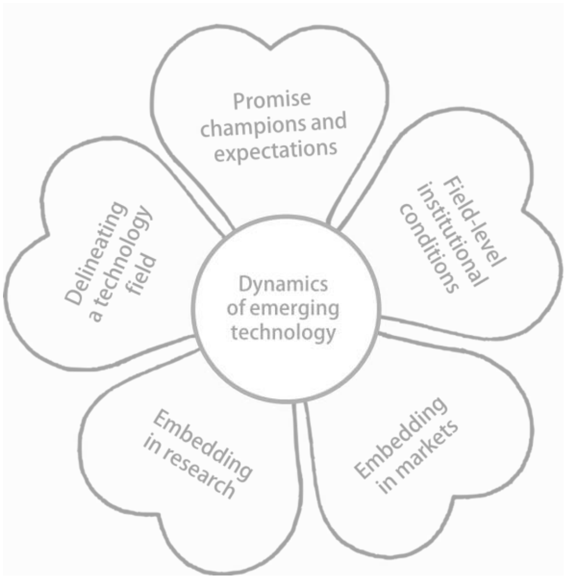
Mapping and characterising the dynamics of emerging technologies to inform policy

Final Report v1.0



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Introduction

The objective of this report is to try and address a key, and growing, question that research and innovation policies are faced with: how to characterise “emerging technologies” in order to define relevant policies.

EU policy is an excellent marker of the increasing interest for such issues: the European Research Council (ERC) was created at the beginning of last decade with a clear objective: to push for what was then labelled as ‘frontier science’; and Horizon 2020 enlarges and broadens this remit with respect to emerging and challenging technologies with the recognition of Future and Emerging Technology (FET) as a fully-fledged programme of its own.

These debates are not specific to Europe; similar debates have occurred in the US about the critical importance of new ‘paradigms’ to enable research to address changing challenges, and this has given rise to new definitions (e.g. *transformative research* or *translational research* in life sciences) and to new organisations (E-Arpa for energy following the long standing DARPA for defence breakthrough innovation). Classical agencies like the National Science Foundation (NSF) and the National Institute of Health (NIH), sectoral departments (like the Department of Energy (DOE) before the creation of E-ARPA) have developed new criteria for selection, and new mechanisms to address these issues (Laredo 2014).

This is not only a political interest, it also mirrors a growing interest of scholars in all fields concerned with technology as well as in social sciences (see table 1, extracted from the working paper by our SPRU partners, Rotolo et al., 2015).

However, it is very difficult to find conceptual frameworks that can interpret breakthrough developments; those expressed in official reports remain mostly based on traditional approaches to analysing mainstream technology. Moreover, often approaches developed for mainstream areas are applied to areas of breakthrough technologies - the blurring of ‘frontier research’ with ‘excellent research’ in the ERC is again a good illustration of this state of affairs. And the selection criteria and processes adopted by the ERC are a further indication about the difficulty of defining conditions and policies that can help researchers and innovators to break from ‘mainstream’ / ‘normal’ science or existing ‘dominant designs’ (to use the parallel languages of Kuhn and Tushmann). In their attempt to find a definition for emerging or breakthrough technologies, our SPRU partners (Rotolo et al. , 2015) have undertaken an extensive review of the literature (some 500 papers in social sciences). They identify 5 major dimensions: radical novelty, relatively fast growth, internal coherence, prominent impact, and uncertainty/ambiguity (see table 2 for their occurrence). This drives them to a definition that serves as a guideline for this research:

"a radically novel and relatively fast growing technology characterised by a certain degree of coherence persisting over time and with the potential to exert a consider- able impact on the socio-economic domain(s) which is observed in terms of the composition of actors, institutions and patterns of interactions among those, along with the associated knowl- edge production processes. Its most prominent impact, however, lies in the future and so in the emergence phase is still somewhat uncertain and ambiguous"

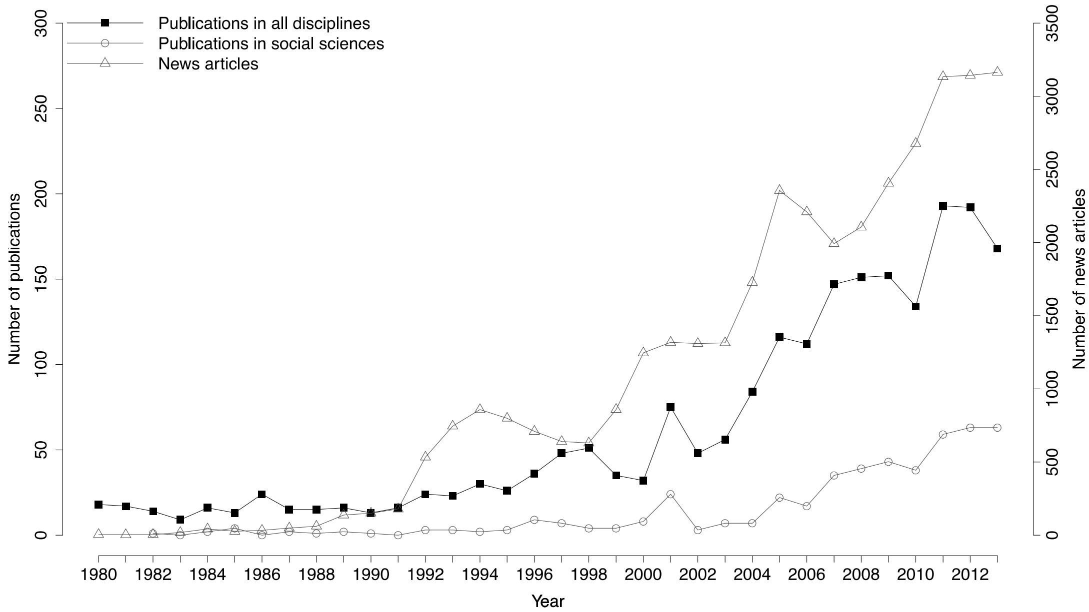

Figure 1: Publications (left axis) and news articles (right axis) including the variations of the terms "emerging technologies". Publications were retrieved by querying SCOPUS data: *"TITLE("emerg* technol*") OR TITLE("emergence of* technolog*") OR TITLE("techn* emergence") OR TITLE("emerg* scien* technol*")"*. Publications in social sciences were defined as those assigned to the SCOPUS categories "Business, Management and Accounting", "Decision Sciences", "Economics, Econometrics and Finance", "Multidisciplinary", "Psychology", "Social Sciences". News articles were identified by searching for "*emerg* near2 technolog**" in article headlines and lead paragraphs as reported in FACTIVA. *Source: search performed by authors on SCOPUS and FACTIVA.*

Figure 1 – publications dealing with emerging technologies, and attributors of emerging technologies (Rotolo et al. 2015)

Table 4: Attributes of emergence and reviewed key innovation studies.

Attribute of emergence	**Innovation studies defining emerging technologies**											
	Martin (1995)	Day and Schoemaker (2000)	Porter et al. (2002)	Corrocher et al. (2003)	Hung and Chu (2006)	Boon and Moors (2008)	Srinivasan (2008)	Cozzens et al. (2010)	Stahl (2011)	Alexander et al. (2012)	Halaweh (2013)	Small et al. (2014)
Radical novelty											x	x
Relatively fast growth							x	x				x
Coherence		x					x		x	x		
Prominent impact	x	x	x	x	x		x	x	x	x		
Uncertainty and ambiguity		x	x		x	x		x	x		x	

Source: authors' elaboration.

Figure 2 - Five attributes of emergence (Rotolo et al. 2015)

Rotolo et al (2015) undertook a review of approaches proposed for addressing these 5 characteristics (figure 2). They identify 55 methodological papers (most being scientometric studies). Their work implies that these methods deal mostly with retrospective analyses, and help detecting emergence, but fail in characterising it.
This gap clearly marks the reason for, and defines the focus of, our project: what it is to characterise emergence, what should we consider, and how can we operationalize it.

A focus on emerging technologies requires that we describe our starting point to position the current discussion on technologies. The next two sections elaborate about the ways in which we consider both technology, and emergence.

a) Some initial points about the focus on technologies.

There is a broad definition of technology that encompasses all aspects of the development and production of new products, processes and services, what the OECD and most economists now call "innovation". This first approach is at the core of most developments on innovation systems, and this is especially visible in the approaches developed by Carlsson (technological systems) and Stankiewicz (design spaces). There are also more narrow definitions of technologies that focuses on the knowledge that enables designing new products, processes and services. Dosi has used the notion of 'technological paradigm' to capture the fact that any industry at a given time relies on a set of shared ways of designing new products (the dominant design proposed by Tushmann). They build the rules and routines that enables actors within that technology paradigm to define and address problems. One implication of this is to make a distinction distinguishing "technology" from products and systems, where products and systems often integrate multiple technologies. The latter point was integrated in management studies by the development at the turn of the 1990s of the notion of firm 'core technologies' (Leonard-Barton, 1992): a firm cannot master all technologies included in its products and is driven to focus on those that the firm considers critical (and on which the firm needs to be at the frontier), leaving the others to its suppliers. Such a definition entails that a technology to exist in a stable way, requires 'shared' rules that are produced, circulated and periodically updated. In this report we argue (see chapter 1) that, like a scientific discipline, there is a core set of shared assumptions about the key characteristics of a technology, there are recognised curricula in order to train a new specialised workforce, and there is a deepening of the knowledge base (building a new academic speciality or discipline – mostly within engineering); but, like for industries and product development, there is also the need for a professional community that cares of aspects of safety and inter-operability.

Box 1. Technologies and types of research activities

"The concept of technology incorporates (at least) two interrelated meanings. First technology refers to material and immaterial objects – both hardware (e.g. products, tools, machines) and software (e.g. procedures/processes and digital protocols) – that can be used to solve real world technical problems. Second it refers to technical knowledge, either in general terms of in terms of knowledge embodied in the physical artifact" (Bergek A. et al, 2008). Bergek et al studying technological systems include both of these definitions. We propose to only consider the second one in our analysis.

This links with a post-world war II definition of technology as 'applied science', e.g. "Technology is properly defined as any application of science to accomplish a function. The science can be leading edge or well established and the function can have high visibility or be significantly more mundane but it is all technology, and its exploitation is the foundation of all competitive advantage" (Project Socrates, e.g. Smith E., 1988).

More recently, studying the impacts of European programmes, we have proposed the notion of "Basic technological research" (Source: Callon et Laredo (1997) to consider their main output: Basic technological research (BTR) … is mainly devoted to the elaboration of new methods and a large share of its outputs is made of computer models and the simulations, which go with them. This establishes a new relation between theoretical work and experimental activities: instead of realizing complicated and costly experiments, the validation of the concept and the design studies are carried out through the development and use of mathematical models. This development results in two complementary types of output: first, new knowledge which needs to be evaluated as such by peers (e.g. definition of physical mechanisms on which models rely) and thus drives towards numerous scientific publications; second, measures and information specific to a given productive activity, which are localized in participating companies and which they may, later, use in their in-house innovative efforts".

b) Some initial points on emergence

Emergence deals with 'breakthrough' science or technology (S&T) that breaks from 'normal science' or dominant technological paradigms - we borrow the terms of both Thomas Kuhn and Giovanni Dosi, both terms share an evolutionary view of S&T. The 'normal state of affairs' is deepening existing knowledge, complementing in an ‘incremental’ way in line with the prevailing dominant view of the domain under investigation. It is a cumulative process that enhances existing competences. For both science and innovation, we know that this is the core of investments made. A common assumption, often voiced, is that over 90% of research and technology activities are cumulative and incremental. Following this assumption, it means that at best 10% of S&T investigations are breaking from the shared dominant knowledge base. The ambition of those active in this 10% is to propose a new paradigm (new dominant design, new rules and routines of investigation etc.) on which to build the knowledge base, at least partly, *de novo*. This can be wide ranging such as when Einstein developed the general theory of relativity or it can be more localised like when Yves Chauvin developed homogeneous catalysis. There has been ample work to show that, most of the time, such changes happen by combining knowledge coming from distinctive disciplines, thus the emphasis on ‘inter-disciplinary’ research. Emergence deals thus with breakthrough science or technology.

But this is not sufficient enough to define emergence. Some analysts focus on idea generation (like in the two illustrations just cited for Einstein and Chauvin). Emergence goes beyond this point. The new idea must have raised interest of other S&T actors, a number of actors must have taken it up and promoted it in order to convince so that the idea circulates and becomes a topic of interest for agenda setting: in science, in policy or in markets. It is only then that strategists and policymakers are confronted with these ‘emerging technologies’, with their potential for explaining and solving, now potentially differently recognised, problems; and they have to decide whether or not they concentrate resources and accompany the actors to demonstrate the potential and interest of this idea of a new technology or to invest in other options.

Box 2. On transition theory

Transition theory developed by Frank Geels and colleagues proposes a multi-level approach to new socio-technological paradigms, with: (i) ‘protected spaces’ in which the new technology is further developed and tested (e.g. large wind mills technology and rules of operation), (ii) socio-technical regimes when a first generalisation occurs in given markets (for example, in Europe with the EU directive for state intervention and specific legislations – at first pushed by Germany and Spain), and (iii) a socio-technical landscape where the overall societal values include the fact that the technology it as a normal solution for energy production, adding to, replacing or transforming the conditions of use of pre-existing technologies (in this case nuclear mainly).

In this multi-level approach, technology emergence in our definition taken in this project, happens at two moments in the process: (a) one is linked to the *creation of ‘protected spaces’* and (b) the other is helping in the *transition toward a new ‘socio-technical regime’*

For this, actors need to assess the situation of new candidate technologies, and when the assessment is positive, to develop activities[1]. The objective of this project and report

[1] We have already mentioned that tools used by funding agencies have been widely criticised. In a way they face similar problems firms face with cumulative and breakthrough innovation. In previous work we have shown that firms need to develop different approaches to the management of both (see Duret,

is to develop an approach to such assessments. In this report, we tackle this in three steps. We first recall what we know about stable states of affairs (in science and in innovation concluding with technologies) and the tools to characterise them. We secondly discuss what we know about the dynamics of new knowledge production and the conceptual framework we propose. Chapter 3 presents a two-stage process (based on 5 analytical steps) that operationalizes this framework and offers a pragmatic set of tools and approaches to assess a given situation.

c) The structure of the report is thus the following.

In chapter 1, we attempt a synthesis of how to characterise 'stabilised' situations (in the same sense that Callon proposes of 'stabilised' networks') and how the questions of 'overflowing' and of 'transiting' to a new stabilised situation are addressed.

In chapter 2, we propose a framework that moves from the micro level of individual initiatives (may it be a researcher or a heroic Schumpeterian entrepreneur) to the collective level where 'spaces' are shaped for enabling the initiatives to deploy, and for gaining 'interest' and eventually 'aligning' other actors. This will help build the conceptual framework we propose.

Chapter 3 will operationalize this framework proposing a 'five petals' approach dealing based on the delineation & socio-cognitive dynamics, field level institutional conditions, promise champions and the role of expectations, research 'embedding' and 'market 'embedding'.

Latour, Laredo et al., 1997; Laredo, Rip, Shove et al., 2002).

Chapter 1 - What we know about stable technology fields and spaces

The ambition in this chapter is to provide an overview and take hold of what we know about the ways in which science and innovation evolve.
We do it in two complementary sections dealing respectively with what we know about fields in science (we explain why we prefer this term to disciplines) and what we know about innovation processes and the development of new markets.
Both sections are organised in the same way: we first look at the key lessons learnt about characterising a field or about innovation processes, then move to the characterisation of organisational/institutional aspects that enable collective action to take place, and finally in a third sub-section we address ways in which the above-mentioned aspects can be visualised, measured, and indicators built. A last section will further elaborate about how we approach 'stabilised' technologies.

> *A word of caution should be made to the reader: this does not aim at providing an overall synthesis of what we know (as is expected from a classical review); rather this is targeted towards our goal, that is take into account all that is needed for developing an approach and the corresponding set of tools that enable an assessment of a given technology and where it stands, with the objective of helping the definition of relevant ST&I policy actions.*

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1.1 What do we know about fields

There is a rich literature about the dynamics of science as a process of never-ending specialisation, where disciplines are the central feature around which research activities and professional identities are organised. In this understanding, long-term dynamics are based on the periodic redefinition of prevailing borders, meaning that the emergence of new disciplines is seen as specific re-arrangements of elements of previous disciplines (thus the importance often given to inter-disciplinary research as a lever for breaking with existing cognitive arrangements and shaping new ones).
In order to avoid the debate about what is and what is not a discipline, Maria Nedeva, after others, has proposed the notion of a 'field' as representing the cognitive constructs that tie together scientists or researchers; others have proposed the notion of epistemic communities (Nedeva 2013, Luukkonen and Nedeva 2010).

1.1.1 Six key attributes for characterising a field

What are the attributes that enable one to identify such a field or epistemic community? We see six central ones that are strongly interconnected, and together build a field. The order we present them does not translate into any hierarchy or degree of importance.

1. A field is gathered around a set of cognitive problems that are shared and together these shared problems form its 'research agenda'. It relies on a core set

of cognitive assumptions (the Kuhnian scientific paradigm) that differentiates it from others (within an established discipline or more broadly).

2. A field also shares ‘technical norms’ of how research should be conducted to produce new recognised knowledge, what Pickstone (2001) calls ‘ways of knowing’ and that which Lamont and colleagues (2006) have demonstrated as being a central issue in handling ‘inter-disciplinary’ projects.
3. A field does not exist in isolation. Bonaccorsi (2007, 2008 and 2010) has proposed to consider three ‘complementarities’ that characterise the types of linkages that connect fields together. These complementarities are cognitive (the other fields you need to interact with to conduct one’s own research), technical (the facilities and equipment required, especially whether or not collective instruments are required that build what has been labelled ‘big science’), and institutional (whether researchers from different environments and with different foci are required – e.g. from the world of firms or hospitals)
4. The knowledge produced requires places to be discussed, ‘certified’ and distributed: conferences and journals build the tangible infrastructure of the ‘invisible colleges’ highlighted by Diana Crane (1972).
5. The dynamics of a field is cumulative, deepening and enlarging the knowledge base (to follow Kuhn again, building ‘normal science’ (Kuhn 1962)). There are two key dimensions that nurture this dynamics. One is substantive and links to the ways in which deepening one problem drives to the identification of new problems, so that the dynamics is for a time, one of multiplication of problems to address, and of people and resources to mobilise. The other is the articulation between knowledge production and use, where we have moved from ‘science’ as a pool in which economic and social actors fish when they need it, to a situation where knowledge is co-produced between heterogeneous actors, universities and firms being the most frequently highlighted cooperation pattern (but by far not a unique one, or even the most important one).
6. The last key attribute lies in the reproduction / enlargement of research capacity (the PhDs and post-docs that populate labs) and in the wider embedding of the knowledge in society, taking hold of the inherent ‘tacit’ dimensions of science in the making and of the critical role of trained people in the development of societal and economic actors’ ‘absorptive capacities’. Thus training, its institutionalisation at wider level and its embedding into universities is a key feature of established fields.

1.1.2 'Spaces' of deployment[2]

The existence and dynamics of fields rely however on the existence of researchers that specialise in these fields, and on the ways in which they can access resources. These are conditioned by the institutional and organisational settings, which 'accommodate' them. These depend both on institutional and organisations dimensions that are more or less conducive to involvement.

Institutional aspects are well known, and we consider three aspects as central: (i) the locus of research activities can be linked with or separated from teaching activities (PROs vs universities); (ii) the access to resources may be hierarchical (through 'core funding' to performing organisations) or competitive (through funding agencies); (iii) careers (and the time at which permanent positions can be obtained) widely differ between countries.

Organisational aspects deal with the embedding of the field in individual organisations, may they be universities or research institutions: as part of their cognitive priorities (and thus visible in the discourse of the organisations) and as translated into structural features: with specific departments or not, with field related labs/centres/institutes or not, and with specific curricula or not.

Maria Nedeva has suggested that this builds a fully-fledged second dimension in the analysis of the dynamics of knowledge that she qualifies as a 'space'. Focusing on institutions, she explains that an important underlying dynamic in the creation of the ERC was linked to the relations between fields and spaces: an increasing number of fields can no longer be accommodated within individual member states, and thus requiring a wider level 'space' in which resources are deployed to address a field's 'research agenda'.

There have been a number of studies about the relationship between 'spaces' and the capabilities of organisations to be 'autonomous' with a view to developing their own strategies be it in term of organising activities, recruiting and employing people, selecting the areas in which they invest, building their financial equilibrium between core funding, student fees, fundraising and research grants and contracts. The 2020 vision of the EU underlines this dimension, calling for a European Research Area (ERA) made of 'strong organisations'. Still we observe a tremendous intra-country differentiation, especially in term of universities and more broadly higher education institutions (Paradeise et al. 2009, Paradeise and Thoenig 2013). This has driven analysts to question the existence of a limited number of archetypes both of universities and of public research institutions, and to approach a given 'space' as a specific combination of these different types[3]. This wide differentiation has been well illustrated

[2] In this presentation we focus on public research,that builds the overarching part of 'certified' knowledge as mirrored by organisational affiliations of publishing authors in the WOS or SCOPUS.

[3] This explains why the new European research infrastructure on research and innovation (RISIS, 2014-17) dedicates important efforts to the construction of two articulated datasets/registries on European universities and PROs.

by the booming of rankings showing how different organisations are from one another: university rankings (like the now well established Shanghai ranking produced by the Jiao Tong university) are not the sole ones, European public research organisations (which are not part of it) are using rankings made by the ERC about levels and rates of success (e.g. CNRS) and are asking for a 'public sector research' based ranking[4].

Taking into account both dimensions shows very clearly that situations cannot be considered 'globally' (for all research fields together) and that the variety of a field's 'productive configurations' is to be connected to existing 'spaces' to capture dynamics. Colleagues, working on ERA-Nets (Van den Besselaar, et al 2007), provide a beautiful illustration of how institutional and organisational dimensions matter in the possibilities of given fields to deploy. The comparison between two chemistry related ERA-Nets illustrates this quite clearly. One ERA-Net linked to the larger EU countries (Germany, France and the UK) considered that the only feature that was problematic lied in new human resources and had thus constructed itself around the circulation of young scholars, so that they could be recruited in the 'best places'. The other ERA-Net, focusing on catalysis, considered that the central issue was linked with university-industry relations (in a field where multinational firms are central) and that there needed to be an intermediating platform at European level where agendas and programmes should be discussed. In both cases, fields dynamics are related to specific institutional features (size of the specialist population in individual spaces, modalities of interaction with multinational firms, etc.) that forbid an adequate handling of the field research agenda in 'existing' spaces, and call, to follow Callon (1998), for an 'overflowing' of existing frames and the construction of higher-level spaces. In other fields (see studies on biotechnology), there has been a discussion of the relevance of 'lower-level' spaces (at the regional, cluster or city level). Thus 'space' should not be only attributed to countries.

A central conclusion is that there is no 'one size fits all' solution that would connect science and spaces at large, but that these issues need to be considered at field level, looking at how key characteristics of a field match with existing spaces in which research activities take place.

1.1.3 Ways for characterising, differentiating and comparing fields

Thus when developing analyses, it becomes central to consider both dimensions simultaneously, starting from field "requirements".

One central empirical lesson from quantitative studies is that fields and spaces evolve slowly, mostly through cumulative accumulation and evolutionary transformations. This has enabled the development of scientific approaches to characterise them quantitatively and produce descriptors, markers and indicators of their dynamics (Lepori & Reale 2012).

[4] This is an on-going development of the Leiden ranking (see RISIS project)

Scientometrics was developed on the fact that a field has a core set of cognitive assumptions that link to keywords, key authors, key articles and in a number of cases, key journals. This offers as many entries to 'delineate' what is technically called a 'seed', which through the application of now quite established techniques can be tested against the whole set of publications and enlarged in a meaningful way. This delineation is central for defining a 'relevant corpus' from which all types of maps and measures can be developed in a static or in a dynamic way (Mogoutov et Kahane, 2007 and Kahane et al., 2014). Classical analyses deal with the size, population and knowledge composition of the field. They also can address their internal and external connections. Thanks to recent developments (Leydesdorff and Rafols), these fields can be positioned in the wider 'map of science' that is regularly produced. These tools enable cognitive analyses of field deployment, cognitive-based network analysis and social analyses of ways of producing (based on collaborative patterns of articles published). More sophisticated methods enable to trace extra-field linkages, mostly through collaborations and/or journal analyses. Institutional analyses of co-authors enable to track institutional complementarities. However, scientometrics remains quite poor in tracking 'technical' complementarities (that is the use of shared equipment (apart from ad-hoc manual field based treatments).

More qualitative analyses enable us to identify whether a field has generated a specific space for publication (the set of journals in which publications take place, the existence or not of a core set of specialised journals…). They also enable following the emergence and 'institutionalisation' of field-level conferences (the number of conferences and their geographical coverage is often an important marker of the degree of stabilisation).

It is more difficult to follow at field level, flows of newcomers in research (as a proof of the training capabilities and attractiveness of a field) and even more to follow the building of human resources that circulate within society.

This is why more institutional analyses are also being developed. Important features deal with the ability of the field to cross 'spaces', the variety in the degree of involvement /specialisation of different spaces, differences in the degree of concentration (vs wide coverage) between spaces, the existence and location of 'places of excellence' (and their evolution over time). A complementary approach is to focus on key authors[5] and their organisations to measure how deeply the field is embedded in the organisations (titles, courses, curricula, labs, organisational discourse).

There is clearly an imbalance in quantitative developments between field characterisation and its organisational embedding. There are also initiatives to develop the ability of researchers to characterise their data sets and thus the fields they analyse (one is the Cortext platform developed at IFRIS, and now one of the facilities embedded

[5] This notion can be understood differently. One way is to consider highly cited authors (the top 1% or even 0,1%) but this tells more about the origin of the field than its deployment. In recent work (on the dynamics on nano S&T, we have focused on the 10% most cited considering them as a key resource in circulating the approach and in exploiting it to the level it can percolate more widely (especially for being incorporated in developments and innovations).

in the new European research infrastructure on science and innovation studies, RISIS). The organisational approach is still mostly addressed through ad-hoc approaches, while we consider it central for policy-making purposes. The report will present some of the experiments developed and/or tested within the project.

1.2 What we know about innovation processes and the creation/development/ evolution of markets

There are multiple ways to enter into this issue. Our entrance point on markets is focused on the assumption that innovation is the development and use of new products, processes and services. There are classically two complementary ways to look at such processes of emergence of new markets and/or transformation of existing markets. One is to focus on the innovation process and the other to focus on use (adoption and diffusion).

1.2.1 Lessons from innovation processes

On the first side, we face a similar divide as with science, between incremental and radical innovation with the latter being also called *breakthrough* or *disruptive*.
Incremental innovation describes the vast majority of innovations and of innovation activities in firms. They are based on an existing 'dominant design' (Tushman and Anderson (1986), an example of this is thermal combustion engines for the car industry) or 'technological paradigm' (Dosi 1982). The work is then cumulative based upon existing routines often embedded in specialised services in firms, and shared ways of solving problems at the industry level. We face a progressive process of change, where accumulated knowledge and practices play a large role in maintaining actors' positions.

However innovation scholars have mostly focused on the rare cases that promote a new 'dominant design', reshape relevant competences (often destroying previously central ones, as would do the generalisation of electric cars), enable a rapid (and sometimes quite important) reshuffling of industries (with the emergence of newcomers and need for drastic strategic redefinition by incumbents), redefine markets (see the telecommunication markets with mobile phones) and their relations to proximity markets (see i-pod and i-tunes and its effects on the music industry).
Focusing on the latter, we have progressively learnt since the beginning of the 1980s that the process is seldom linear, seldom internal to the firm and that within firms it is seldom limited to a specialised service. Concepts like the chain-linked model (Kline & Rosenberg), the role of lead-users (Von Hippel 1986), techno-economic networks (Callon et al. 1992), distributed innovation processes (Green et al 1999.) have translated this progressive accumulation of knowledge about innovation processes that the now established notion of 'open innovation' (Chesbrough 2006) subsumes.

Studies have focused both on individual innovation networks at the micro level and on shifts that occur at a collective level (most often the industry or a set of inter-connected industries).
At the individual level, they have pinpointed the importance of users and the multiple ways in which the latter can be involved (few have also underlined, especially for small start-up firms, the pitfalls associated to such involvement).
They have shown the difficulties firms face when having to dismiss/destroy part of the existing knowledge base, and for absorbing and mastering internally new knowledge. They have shown that this goes along with an explosion of collaborations and with a growing call for external problem-solving sources of knowledge, often addressed by a new type of KIBS in what could be categorised as 'business to research' models (as opposed to classical B to B and B to C models).
But, even more importantly, they have highlighted the growing complexity of products seen more and more as 'complex systems' that require both integration capabilities and specialised actors in system components. This has driven to a 'fragmentation' of innovation processes (often associated – but wrongly in our view – to outsourcing), to the transformation of 'suppliers' in co-developers and to the emergence of complex value chains in innovation (and not only in production). Value chains have even become 'longer' with internationalisation and the multiplication at each stage of the value chain of competition and technological variety.

For promoters of these new products/systems or components/systems, such moves are not easy (see the inability of Kodak to adapt to the numerical revolution invented in its labs), and authors like Christensen (2013) have suggested that this explains the rise of 'new technology based firms' (NTBF, later called start-up or spin-off firms) as a major source for demonstrating the value of new designs and of renewal of industry populations.
For incumbent firms, the development of new products-systems has led to new challenges dealing with the identification of their 'core capabilities' (and also the core capabilities of their suppliers-developers), with the coordination of multiple actors and with the emergence of a new set of integration / architectural competences and with new approaches to the management of such processes: authors like O-Reilly have spoken of 'ambidextrous' firms, and we have suggested the need for a distinctive management process within firms[6].

Studies have also shown a growing differentiation between the acquisition of technologies and innovation processes *per se*. They have highlighted the explosion of university-industry relationships but an even greater explosion of inter-firm collaborations on new technologies. Also observed has been a shifting of approach to 'co-optition': where competition is focused on products per se, cooperation has become the rule rather than the exception in most sectors for new technology developments, the

[6] See the PROTEE and SOCROBUST projects and methods for managing breakthrough innovations (Duret et al. 2000, Laredo et al 2002)

danger being not to share technologies with competitors, but to be barred from access to the specific technology option that fit the new product the firm wants to develop.

1.2.2 From individual networks of innovation to the collective shaping of markets

We now move from the individual to the collective level of radical innovations[7]. Different concepts such as sectoral systems of innovation or technological systems have been developed to capture industry-level transformations.

Stankievicz (2000) looking at these transformations and the way they reconfigure pre-existing industries has proposed the notion of 'design space', where firms share ways of knowing and doing things, and where the qualities of these things are collectively built and recognised, often in a wider collective including representatives of targeted user groups. This builds also the collective level at which issues of security, safety and inter-operability can be addressed. This links with the works on the sociology of markets that consider that there is no such thing as a 'natural' market only made of the encounters of buyers and sellers, that markets need to be organised, globally through transversal regulations (laws on property and exchanges) and specifically for individual markets by guarantying the safety of workers, the security of users and the inter-operability of objects within the market, may this be through regulation or standardisation.

Three complementary developments are here quite important. The first one is the characterisation of 'design spaces' by the type of knowledge that characterise them. Asheim (2007) and colleagues have proposed to differentiate three types of knowledge: (i) analytical (based on scientific and technological developments), (ii) synthetic (based upon integration or architectural capabilities that are most of the times learnt through experience and are idiosyncratic to individual firms), and (iii) symbolic (associated to the values borne by both the firm and the product, such as Apple and the i-phone). The issue is then less to link individual markets to one type of knowledge, but to a specific blend that explains the conditions under which firms are more or less competitive and gain or lose market shares; it also helps understanding the possible strategies by firms to differentiate themselves and gain specific positions in given market segments.

The second development is more dynamic. Authors like Courtney et al (1997) have shown that there is a continuum between the individual and collective levels: firms that

[7] Here we must take into account Abernathy's classification of radical innovations, by exploring two critical dimensions: the relations with technologies and the relations with markets. No change in both characterises incremental innovations. The other three situations represent different types of radical innovations: radically different ways of producing products while not changing anything in the relations with the market (Dyson is a good illustration of this), radically different ways to access customers without changing products (the web has multiplied such possibilities, the hypermarkets were such a transformation 40 years ago, we speak today of new business models), and what Abernathy called 'architectural' innovations where both the technology and access to products were changed (the i-pod and i-tunes being a good example).

want to push radical innovations need to develop ‘market shaping activities’, that is convincing other firms of the shifting rules (what actors are allowed to do), norms (what they ought to do) and values (what they want to do). Similarly those market framings that work for a given time, have always been built on a given set of compromises (what is considered and what is not, how different aspects are valued), and these may be questioned again when the market is generalised, driving stakeholders to ask for a reframing to take into account and to internalise these aspects that were excluded or not anticipated (externalities in economics). Callon speaks of an endless dynamics of market framing and overflowing.

The third development focuses more on the early stages of emergence: how can heterodox knowledge and breakthrough technologies prove their usefulness? Why should they be considered interesting new options? There has been a set of works that highlight the role of public policies in generating variety (Callon has even proposed that this was the main reason for policy intervention to avoid lock-in situations and their classical dynamics of oligopolisation over time). In the early study of a new IT options that we shall further analyse later, we have shown how different policy instruments are required for wide ‘exploration’ and for ‘crystallisation’. Other colleagues (Rip and Kemp (1998) in particular) have underlined the role of policies in creating ‘niches’ (or ‘protected spaces’) that enable testing certain key dimensions, and entering in a learning process, while not considering other aspects (e.g. cost issues). One central question that specialists of transition theories (and in particular Geels 2002) have put forward is the way through which potential breakthrough innovation can get out of their niches and enter a diffusion process in society. Knowledge on these transitions remains quite limited and not very illuminating: analysts of dominant designs speak of a fluid phase where designs multiply and of a selection process that will progressively establish a dominant design; analysts of innovation journeys (Van de Ven 1989) consider that at one time there will be a narrowing process that will enable to move from exploration to exploitation (March 1991); Geels speaks of a progressive alignment of values and qualities that will enable to move from the micro level of individual ‘want to be innovations’ to the meso level of established markets. We (Delemarle and Laredo 2014) have proposed a different approach, considering, as Courtney, that market shaping requires strong investments by concerned actors, that this is one dimension of the work that takes place in niches that has been vastly underestimated, and that the issue is to promote the adequate set of rules, norms and values that will enable the market to emerge. While some are intangible (embodied in the way actors behave), most are embedded in physical equipment, in formalized processes that build on specialized certification and validation bodies, or/and in legal obligations (with corresponding legislative and enforcement structures). Following Fligstein 1996, we have proposed to call these ‘market infrastructures’. Innovation can move out of their ‘protected spaces’ when relevant market infrastructures have been built enabling a first diffusion process.

1.2.3 Focusing on diffusion: linking with the collective dimensions associated with early market deployment

Another entry point to innovation is linked to the diffusion of innovations. The focus is less on where does the idea come from and how it is transformed into a first development, but to focus on the diffusion process: how a first market is established and how the use of the new innovation (or set of innovations) becomes generalised. Rogers (first edition in 1962, the most cited author in innovation studies) has shown that we face a complex and long process with 5 main stages. At both extremes, we have the phase of initiation and the phase of routinisation, corresponding to product diffusion (and adoption)[8]. What is important for our purpose, lies in Rogers' decomposition of the emergence or penetration of the market in three phases: upstream a 'matching' phase whereby the possibility of a potential innovation is tested; and downstream a 'clarifying' phase where the conditions under which the product can generalise are stabilised. In between, interestingly he locates a phase of 'redefining and restructuring' that is explained in term of constructing the internal and external conditions for the market to exist, insisting on organisational dimensions. This links perfectly with the notion of transitions and the two activities we have proposed for niches: on one side the testing and refining of the future innovation (or set of innovations), and on the other the construction of the relevant market infrastructures that enable a first deployment.

1.2.4 Ways of characterising dominant designs and their evolutions

However, most of what we discuss when we discuss innovation are evolutionary, cumulative, incremental innovations. This has mostly been studied at the micro level within firms as a management issue, and this has driven to an explosion of works on project management based upon the optimisation of 'time to market' and of the intervention of multiple actors within the firm and beyond[9]. Far less work has been devoted to addressing issues at the collective level of a dominant paradigm. Industrial economics have addressed the issue of differentiation and segmentation as a strategy by firms to avoid price competition, and authors like Nooteboom (1999) have shown how this movement of variation was critical in providing seeds to new paradigms.

Classical policy work has underlined situations of market failures that require public intervention. Three main avenues have often been used: direct project-based support to individual firms (through grants and/or soft loans, e.g. OSEO), collective support via an industry-targeted technical body (e.g. technical centres in France), indirect support

[8] Numerous works have further detailed this phase looking at early adopters and laggards, generating what Vernon has later theorised as the product cycle, and connected it to internationalisation processes (see Laredo 2013 for a review).

[9] More and more this has had to consider the engagement of actors beyond the firm, which raises a number of new problems (cognitive about the ability to share problems and ways of doing things, organisational about how to conduct projects and interact, legal in particular about intellectual property rights, and strategic since engaging in joint development presupposes engaging in later production activities).

(mostly through tax credit or public procurement). Since the 1980s and the emergence of debates about the accessibility of public research by firms, a new set of policy problems has emerged and policy instruments developed in order to foster the relations between university and industry: collaborative programmes (or technological programmes to follow Callon et al., 1997) have become a major policy instrument both at national and even more at EC level. Similarly more and more emphasis has been given to capability building and the role of higher education (both for initial training and lifelong learning). And since the beginning of the 2000s there has been a renewed policy focus on norms and standards as a key activity supporting the evolution of industries (see for instance the 2006 Aho report).

All these movements account for the importance of policies that deal with the evolution of existing dominant paradigms. How can this be characterised and visualised? We have proposed the notion of 'techno-economic networks' built on three poles 'science, technology and market) and two sets of intermediation activities (see visualisation). It is important to mention that this construct is the outcome of questions raised by a public agency, the French agency for renewable energies (ADEME today, then AFME, see Callon et 1992). The agency has used it at the industry/ technology level (and not at the level of individual innovations). For instance the key TENs were defined around distinctive renewable options (such as biofuels, geothermal energy, photovoltaic energy or wind energy), distinctive equipment industries (such as heat transfer/exchangers, collective transport, the car industry or domestic appliances) or distinctive types of users and their engineering/architectural requirements (like cities or equipment within them: pools, stadiums, schools, etc.). The 'techno economic network' approach was used to identify the three 'poles' that enable the evolution of the paradigm - science, technology and market[10] - and their interactions. The motto for public intervention was: if one pole is missing or 'incomplete', build it; if poles do not interact with one another or if this interaction is not productive, focus on their alignment; if poles are well developed and aligned, interventions are needed only when willing to change the overall trajectory of the TEN (e.g. the car industry and energy saving engines).

Each pole has its own dynamics and may face issues that may require public interventions. For instance, at the market level, ADEME initiated incentives for families to equip themselves in passive solar energy, while a fiscal credit was established for firms to install photovoltaic equipment. Following with the same example, ADEME supported the development of specialised labs through multi-year programmes, in order to insure that France would have what they considered a relevant science capacity. Most of the interventions at technology level were then focused on addressing core problems of the supported technology, often through support of the industry-level technical research organisations (such as CETIM for heat transfers) and through support to adequate standardisation/regulation.

[10] In later developments pushed by policy reasons, ADEME added a regulation pole (linked to the framing of markets, see section 2) and some other developments (like Bell, OECD 1994) considered also adding a financial pole (especially when dealing with start-up firms and venture capital).

However for the network to be performative, interactions between poles are critical. This is what theory about innovation systems underline. University (public research)-industry interactions are a well-known dimension often addressed through ‘technological programmes’ dealing with collectively recognised mid-term issues faced, and through the involvement of firms in training (e.g. in teaching, through internships and stays, through apprenticeship or through involvement in shaping curricula). Often these relations are mediated by intermediary organisations (whatever their terminology: technical centres, technology resource centres, collective industrial research centres…) that also act as key actors in the shaping of the core technology. They also act as mediators between the core technology and specific applications developed by individual firms by providing support to prototyping and/or testing facilities. Most policy interventions tend to focus on the science-technology linkages. However recent policy developments insist on the technology-market linkages. One good example is linked with the development of quality labels that help individual users to invest (e.g. ‘flamme verte’ label for wood stoves or the qualifelec label for installers backed through professional training and a certification process).

The TEN has thus been developed as a good visualisation of an existing or want to be dominant paradigm, exhibiting the different ‘technology’-oriented dimensions to consider. It highlights the main poles that are needed to maintain the paradigm and their interactions. It focuses on the activities and the products they put into circulation, the latter being central to the interactions between, and the alignment of, actors. One major difficulty faced with is that very often, actors are active in more than one pole of a given TEN, so that the characterisation has tended to differentiate between the functions and functioning of TENs and the actors that are enrolled and aligned. A further difficulty is that actors (especially large ones) are involved in multiple TENs at the same time, and taking this into consideration entails a higher level of articulation, beyond the restricted notion of a ‘dominant paradigm’ associated with one industry. We shall specifically address this issue in the following section.

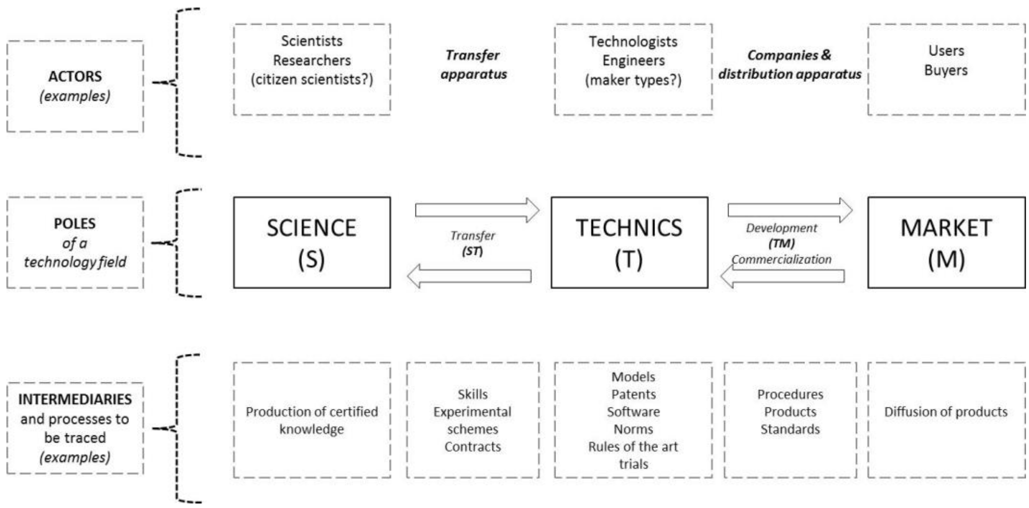

Figure 3 – Techno-economic network poles (Callon et al. et al. 2015)

1.2.5 Indicators and tools for characterising the evolution of TENs

The visualisation proposed by TEN is in a way a heuristic helping us to think about the different dimensions of a TEN. It tells us that it is restrictive (and potentially dangerous for policymakers) to characterise the dynamics of a TEN through only one dimension or the dynamics of one pole. It suggests that different approaches are needed to characterise the different poles and their interactions. And it highlights the fact that the overall dynamics of one dominant paradigm depends upon a coherent evolution of the different poles and of their interactions, with the classical motto that the strength of a dominant paradigm lies in this of its "weakest element".

We have already addressed all the tools we have for dealing with the science pole and its interactions with other poles, mostly through the analysis of collaborations between different types of organisations.

Dealing with technology as a central aspect of dominant paradigms, nearly all quantitative studies have restricted innovation activities to invention activities, taking patents as a central marker. This has enabled to apply with patents quasi-similar approaches to what has been developed for publications, technometrics paralleling scientometrics.

The emergence and growth of markets can be followed through the analysis of the population of producing actors (rather than products), using industrial economics. Classical expectations are linked with lasting competitive advantages to first entrants or when facing competing business models to the first to propose the winning business model (cf. multiple cases in web based markets). Market maturation is often linked to a drastic reduction of producers and the stabilisation of oligopolistic actors in the 'core' market, while differentiation strategies enable complementary actors to take key positions in specialised segments.

Most other dimensions, especially dealing with organisational aspects and in particular with intermediation between poles, have been addressed through qualitative studies, most of the times via case studies. Sometimes these have been complemented by surveys to highlight certain aspects (see for instance the evaluations of individual EC programmes, or of the impact of the Framework Programmes on given countries, e.g. Laredo (1995, 1998) or even by econometric work (see developments pushed by the US ATP programmes, for a review see Ruegg and Feller (2004), or the very recent work done by the ASIRPA project, Joly et al., 2015).

Chapter 2 - What is known about *breakthrough* technology fields and spaces

In this chapter we organise what is reported in the literature about breakthrough technology fields and spaces. Our focus is specifically on breakthrough situations and dynamics because it encompasses both the development of breakthrough innovations (at the level of a firm) and the development of breakthrough technologies (at the level of an industry). We argue that even if the level of analysis is different (micro vs. meso), many of the challenges faced are shared among the two. The challenge is actually to articulate the two levels. This has long been acknowledged (Schumpeter, 1942; Freeman, 1974; Kuhn, 1962) and materialised in a cyclical model of technological change (Anderson and Tushman, 1990) around the notions of 'paradigm'. Breakthrough S or T aims at replacing a dominant existing paradigm (coined as 'normal science' by Kuhn and 'dominant design' by Tushman) by a new one that re-arranges or replaces existing capabilities (thus being enhancing or destroying). How does a new paradigm 'emerge', how is it tested and how can it diffuse and generalise, are the questions we focus upon in this section.

The section is organised around three sections on visions, champions and spaces. For the first of the three we build upon the Latourian view that every researcher has a world vision when pushing his/her hypothesis. Future worlds are important and, when formalised, expressed in visions and expectations. Visions need actors that 'invent', 'develop', 'circulate' and push for actions enabling their unfolding: this will build the second section around 'champions', better qualified in the literature as 'institutional entrepreneurs'. The third section will deal with the spaces where champions deploy their activities. We shall there mobilise and re-arrange three main streams of literature linked to actor network theory (both on networks and hybrid forums), to political science (and in particular around arenas and governance) and to 'transition theory' in innovation studies. The ambition of the chapter is to present knowledge about the dynamics of breakthrough technology fields that we will put in to action in Chapter 3

2.1 Vision framing and sharing

Mobilising and sharing a vision often implies developing discursive strategies. Kodak could not have imposed the photo industry without his discourse on 'the Kodak moment'. The importance of the discourse in shaping change is highlighted by the 'discourse factory' that Jean Therme developed and managed to support the set up of the largest investment (Minatec for nanotechnologies) for years in Grenoble (Delemarle, 2007). We speak of discursive strategies because the discourse is built to induce action and is nourished by action (notion of 'narraction' proposed by Kahane, 2005). It is punctuated by tests and evolves as networks evolve.

Radical or architectural innovations as Abernathy and Clark (1985) called them, refer to two central dimensions (Deszca, et al, 1999; Colarelli O ' Connor et al, 2001): they generate uncertainty about future uses (market side) as well as about scientific and technological capabilities (production side of science and technology). These are often mixed. First, there is a need for consumers to "learn these new anticipated products" that meet needs that are not yet recognized or formalized as such, and secondly, there is the development of scenarios for firms as a tool for managing uncertainty. Courtney et al. (1997), summarizing the work on risk and innovation strategies, emphasize the need for actors to shape and to share their vision of the industry with others, to align industry actors around a vision of the future market or future of existing markets (Callon, 1992; Bas de Laat, 1996; Rip et al., 2001). The importance of spreading the vision of the use of new technologies has already been shown on numerous occasions during the phases of emergence of technologies such as the role of demonstrations in speed contests at the beginning of the automobile epic (Rao, 1994): they must "make visible" to users the terms of use of the new technology. This same principle of sharing the vision on the deployment of innovations is also found on the side of the supply of technologies and it is particularly strong in complex industries with a rapid rate of innovation such as microelectronics and its roadmap, which coordinates actors' activities (Kahane et al., 2010; LeMasson et al., 2012; Robinson et al., 2012).

If the concept of vision indicates a strong performative connotation, other concepts are mobilized in the literature with the notion of "promises" or "expectations" (Brown and Michael, 2003). Expectations are recognized to play a major role in structuring and legitimizing a new scientific or technological field (Robinson and Propp, 2008; Robinson et al., 2007). They contribute to the enrolment process by providing an image of the future (Brown and Michael, 2003; Konrad, 2006). "They give definition to roles, clarify duties, offer some shared shape of what to expect and how to prepare for opportunities and risks. Visions drive technical and scientific activity, warranting the production of measurements, calculations, material tests, pilot projects and models. As such, very little in innovation can work in isolation from a highly dynamic and variegated body of future-oriented understandings about the future" (Borup et al., 2006). Visions include actors beyond the scientific and technical sphere. Lösch (2006) and researchers using the notion of 'Leitbild' (guiding vision) consider that expectations create spaces of communication between the spheres of science, economics and mass media. Thus, they create links between different dimensions and levels: horizontally between different communities and vertically between different levels (micro, meso, macro).

However, if expectations are not reflected in fact, if the promises concerning the development of technology are not fulfilled, the impact can be significant in terms of reputation and resource allocation, as was the case for biotechnology, e-commerce or stem cells (Brown, 2003; Konrad, 2006). In these cases, disillusionment followed a period of hype (excitation) (Gartner Group, Fenn and Raskino, 2008). Authors that have studied cycles (Ruef and Markard, 2006 or Konrad, 2006) show that the pursuit of innovation activity during the phase of disillusionment depends highly on the institutions that were developed during the phase of hype. To better understand what happens, they propose to differentiate three aspects: frameworks, applications and expectations. The former deal with global expectations that is the role of the new technology in society. Applications, especially those widespread, enable to position the technology in its present development while expectations stricto sensu deal with actors anticipations of the market. The authors suggest that these can have different trajectories in the disillusionment phase and that their combination may explain the effective situations observed.

This leads us to recognise that expectations change over time. Robinson et al. 2007 worked specifically on expectations, i.e. the statements made, and show that there are various effects on the shaping of the field. Indeed, when making a statement in a text, an author connects elements of the technological field together. The authors suggest that looking at specific types of linkages can be used to characterize the emergence of the field itself. In addition, the analysis of the dynamics of one modality over time is useful for characterizing the enrolment of other actors (through its take-up and use). This drove them to propose a classification of the degree of “real-ness” or closeness to becoming reality, by drawing on the literature dealing with expectations (van Lente, 1993; van Lente & Rip, 1998; Brown & Michael, 2003; van Merkerk & Robinson, 2006, Borup et al., 2006) and with vision assessment (Grin & Grunwald, 2000; Grunwald, 2004), from science fiction to proof of concept, illustrating it by examples taken from the early stages of nanotechnology emergence.

Statement linkage modality	**Description**	**Example**
Science Fiction	It may happen (accepted as fantasy). Science Fictions indicate long-term fictional ideas, which are accepted as fantasy without requirements on feasibility	“The dark side of nanotechnology is "grey goo"- The nightmare possibility that "nano-robots" could be programmed to gobble up their surroundings and turn everything on Earth into more nano-robots ” (Park, 2003)
Visionary linkage	It may happen (accepted as reality based fantasy). Visionary linkages indicate long-term technological possibilities, which are accepted as reality based fantasies, which could claim feasibility.	“The behavior of devices at these scales could eventually mean fundamental changes in the way we build things, forcing us to abandon old ideas ” (Cho, 2001).
Guiding vision	It may happen. Guiding visions denote more technical and planable technological futures. The difference between Guiding Visions and Visionary Linkages is that Guiding Visions imply action, although no actor is	“Powering nanoscale machinery by nanosized motors that move by in situ conversion of stored chemical energy is one of the most interesting challenges facing nanotechnology.” (Kline et al. 2005 p744).

	positioned to undertake it (a more general statement).	
Expectation linkage	It will happen	We expect that the successful formation of fully functional surface-mounted rotors will enable investigation of the concerted action of a large ensemble of unidirectional molecular motors, and that this system might be a first step towards the construction of more elaborate and functional nanosized mechanical devices." (Van Delden et al 2005. p1340).
Agendas (goals)	We are going to make it happen	"This paper is the first step towards our goal of creating artificial complex systems composed of large numbers of components that move autonomously and that self-assemble." (Ismagilov, R. F. et al. 2002 p654).
Proof of concept *(proven and/or demonstrated)*	We have made it happen (accepted as fact/reality). Technological developments that have been demonstrated and are accepted as fact or reality.	"Nature already provides us with a wide range of biological nanomotors" (Hess, et al., 2004, p2111).

Table 1 – Categorizing types of visions (Robinson et al. 2007)

2.2 Role of champions to mobilise supports and resources

Visions do not develop on their own. They need to be framed, pushed and circulated. We know from past studies that the presence of a champion is a critical condition of their emergence and deployment. For champions visions serve to mobilise supports and resources. The literature often labels the champion as an "institutional entrepreneur", an entrepreneur who is able to transform the pre-existing institutional structures using specific strategies. One of the most well-known examples is Thomas Edison. Edison was not the inventor of the light bulb (23 inventors developed a light bulb before him); but he managed to convince venture capitalists to support his project, to fund the setting up of power stations and to convince a city to switch from gas to electricity and to organise a set of infrastructures (the distribution cables) so that everyone could use his light bulbs.

Those who champion promising fields of technology, mobilise visions and expectations in different ways, and all are visible when a technology field is beginning to mature.

Promise champions create convincing expectations about the utility and value of the new field, and thus play a strong role building legitimacy for an emerging field. We have made a classification of "champions" (Table 2), which we describe in further detail in chapter 3 with an overarching case of nanotechnology.

Type of champion	**Role they play**	**Comments**
The Cognitive reference	The forefathers of a technology field, often referred to legitimise a field.	Usually recognised after the fact as the visionary(s) who made the initial breakthrough or invention.
Expectations pushers	These are key actors in the early growth phase of a field who develop and push expectations of the field.	Expectations pushers help to build up hype about a field which can cause "expectations niches"[11] which can be taken advantage of by institutional entrepreneurs.
Promissory organisations	These provide visions of the futures, often in the form of projected markets.	These champions may be dedicated to the field (such as Wohlers for additive manufacturing) or more generic vendors of future intelligence (such as Lux Research or the Gartner Group).
Institutional Entrepreneurs	These make use of the umbrella promise to mobilise resources and create arenas, sometimes R&D programmes sometimes physical institutions.	These champions actively forge the institutions that structure the field. One could call these institutional entrepreneurs (Garud et al. 2002)

Table 2 - Four types of promise champion and the roles they play.

What are the conditions that are required to become the effective champion of an emerging technology? The literature has identified four key characteristics, which we examine in turn.

The success in the mobilisation of supports and resources is linked to the **legitimacy** of the champion. Legitimacy largely connects with the **position of the champion in the field**: incumbents benefit from more legitimacy than new entrants (Garud et al., 2002; Hwang and Powell, 2005). In the well-known case of the move from microelectronics to nanoelectronics in Grenoble, CEA, the largest public research centre in the area was the champion of the new technological platform Minatec. Only because CEA Grenoble was a longstanding actor in the region, the largest employer in the city and the sponsor of many previous technological developments could the project be a success (Delemarle, 2007).

Secondly, **the degree of centrality of the champion** needs to be considered: actors central in the existing networks have more chance to succeed than players on the fringe.

[11] "Expectations niches" also called "expectations envelope" are the tentative protection afforded to an emerging field fuelled by hype, hope and sunk investments (Robinson 2008). The latter is important, where even though a technology field may not be emerging rapidly, actors are less willing to give up and more to other areas if (a) hope remains that the field will emerge and (b) the need for a return on investment of resources remains low. Thus, the public sector is more willing to follow expectations for many years, whereas the private sector may employ "waiting games" (Robinson et al. 2012) or pull out all together, as was the case with lab-on-a-chip technologies (Robinson and Propp 2008).

A central position allows to better structure the field, to align heterogeneous actors, to bridge together diverse stakeholders. It also allows to access dispersed sets of resources due to the richness of his/her social capital (Maguire et al. 2002). Going back to the Minatec case, the success of the project is also linked to the position of the local head of CEA Grenoble, Jean Therme. He did his studies in Grenoble, was deeply connected to the local policy makers, was the former head of the most important electronics lab from CEA, was formerly working with the largest company in microelectronics in the region (ST Microelectronics) and was a member of the board of the largest engineering university (INPG). He was thus connected to all actors of the networks: from university, to industry and to research on the one hand; from local policy makers to national and European industry and research policy makers on the other.
Legitimacy is often associated with **power**. Powerful actors have easier access to political and bureaucratic mechanisms than others (Lawrence, 1999). However, they cannot rest solely on their authority to convince others to follow them.
Finally, the champion is characterised by **personal skills**. These skills are developed through the life path of the individual. The success of Christian Blanc (Blanc report, 2005) in changing the French public policy from a set of local development on one side and national industrial 'grands programmes' on the other side to a national innovation policy cannot be fully understood without considering his previous successes both as a policymaker (handling the French Polynesia crisis in the 1980s) and as a manager (taking Air France from near bankruptcy and turning it into the most profitable airline in the 1990s). The champion very often possesses political and social skills (Fligstein and Mara Drita, 1996). Jacques Delors could never have convinced the European Community to break through its internal crisis with his proposal of a Single Market without his personal skills. Looking again at the Minatec success story, Jean Therme's personal communication skills were well known and translated in its multiple presentations to convince the various actors (102 presentations over a 2 year period, which makes one presentation every 3 working days!).

2.3 Spaces of deployment

There has been ample literature to discuss the spaces in which champions develop their activities so as to reach a collective agreement of what the future technology will be, its directions, its uses and the markets it will serve or (re)shape. Two central terms capture the success of such activities at an early stage: the *building of communities*, and the *adoption of roadmaps*. There is also an agreement on the importance of demonstrations (or collective experiments) as a central tool in the simultaneous shaping of both constructs (the community and the roadmap). Lessons also tell us that this takes place, most of the times, in 'protected spaces' (Rip and Kemp, 1998) and that public policies often play a central role in the emergence of such protected spaces (Delemarle and Larédo, 2008).

2.3.1 Multi-level perspectives and spaces

More recently (based on Geels 2002), a stream of literature in socio-technical studies has focused on long-term transitions, questioning a monotonic approach to innovation as proposed by the diffusion literature (based on Rogers, 1962). They consider on the contrary that a multi-level perspective (MLP) is necessary that differentiates between three levels and considers their interactions as central to the realisation of 'transitions': the local constructs at the level of niches (or protected spaces), the regime that is established at the meso level (typically of a market and its corresponding industries), and the landscape level that embeds the wider institutional frames (with a wide definition of institutions, North 1990) that both enable and constrain the shaping and evolution of regimes.

This resonates with developments in organisation studies (Aldrich and Fiol 1994) about the analysis of institutional entrepreneurship, and the need of considering different levels in which activity must be deployed for a new institution to be rooted: the local level (of a project or inside an organisation) and the global level (of the organisational field). Delemarle (2007) further differentiated the global level into a 'strategic' level (the stakeholders directly concerned) and the 'wider environment' (the other actors and rules that might have a say in the type of change promoted).

All analysts agree that a central issue in the success of transitions and/or innovations lies in the articulation between these different levels, and that we should take account of one central lesson of innovation studies: these are not linear (sequential) but whirling with multiple interactions (that can be considered as a series of attempts, and that success is most of the time the achievement of a 'trail of trials'. One critical aspect lies in the ways in which 'required' changes (for the new market to emerge or the transition to take place) are discussed and negotiated. STS scholars (Callon and Rip 1992) have proposed that this takes place in hybrid forums while political scientists (Kuhlmann et al. 2003) have advocated the role of arenas. Both have underestimated the organisational dimensions of such negotiations (Delemarle & Larédo, 2014).

For characterising the emergence of new technologies, four aspects are thus central:

- Delineating the community under construction;
- Characterising the protected space (or niche) within which demonstrations are made and learning takes place;
- Identifying and characterising roadmaps under development or developed, and the future world they promote;
- Identifying arenas and organisational setting where anticipated required changes (compared to present day market/regime) are discussed and negotiated.

The following paragraphs elaborate on these four points as supports for the operationalization proposed in chapter three.

The **building of the community** to support the champion is often implicit in case studies but highly central as the literature on the institutional entrepreneurship shows (Garud et al., 2002; Maguire et al. 2002; Delemarle 2007). Community building is closely related to border definition. This works allows to define "protagonist, antagonist and an audience of uncommitted but potentially mobilised supporters" (Creed et al., 2002: 481). There is however a dual complexity to consider: a new community does not exist as an island: defining borders is also defining relations with pre-existing communities as is well demonstrated by science dynamics. And this happens both in term of content (what are the respective activities and responsibilities and how they connect) and space. The geographical scale comes to complete and complicate the three basic levels proposed by organisational theory (local, strategic and wider environment levels) or transition theory (niche, regime and landscape).

2.3.2 The critical role of protected spaces

The literature on innovation is rich with regards to the need for organising differently for radical innovations. Organisations need to be ambidextrous (Tushman and O'Reilly, 1998) for being able both to exploit technologies and to explore new opportunities. The routines of companies to run their usual business are not meant to promote exploration and "**radical innovation hubs"** (Collarelli O'Connor and Rice 2001) have to be developed to allow for testing and demonstration of new concepts outside of formal financial reporting and evaluation schemes. More widely innovation scholars have promoted the notion of niches, as **protected spaces** (Rip and Kemp, 1998). A protected space is a space in which some constraints are removed to experiment and start enrolling other actors including potential producers and users. Defence has been traditionally a niche for new technologies to be tested removing the constraints of cost before they could be adapted in larger markets. Niches are places in which the cognitive dimension of new technologies can be developed, places in which "knowledge about the new activity and what is needed to succeed in an industry" is developed (Aldrich and Fiol, 1994: 648).

The presence of a champion, while it can play a crystallizing role for community building, is most of the times not enough to generate a protected space. Very often, the **possibility to experiment requires strategic policy intervention**. Two types of public intervention are possible to foster the emergence and the maintenance of a protected space. First, policy instruments can develop a friendly environment for new S&T options. In this case, public intervention is based on procedural policies. Going back to the asynchronous design case, Delemarle and Laredo (2008) provides a clear illustration of this: the existing framework first allowed in 1992 to support the development of the community ACiD (the program provided small subsidies for researchers to travel to workshops and to learn from each other); then through the existing research programs (OMI and MEDEA – both European research programs), researchers had the opportunity to use up to 10% of their budget to test new options (this is how supporters of asynchronous design made their first tests and demonstrators in various application contexts). Second, policy instruments can specifically support one technological option. In this case, public intervention is based on substantive instruments. A good example can be found in the support of Paris to the "blue car". The blue car is Bolloré's electric vehicle. It can be found in Paris and the close suburb. More than 46 cities joined the experiment. Several hundreds of stations are scattered throughout the Parisian region.

2.3.3 Arenas as spaces for negotiating the collective dimensions of new technologies

Roadmapping activities can be argued as spaces for articulating the future and paths towards it, sometimes in firms, but increasingly in collectives (Robinson and Propp 2008, Moretto et al 2014). One clear limitation of both roadmaps and the TEN approach is that, while defining future worlds as viewed by promoting actors, it does not identify the spaces in which characteristics of new technologies (and in many cases with them the prevailing dominant design and the infrastructures of the new market) are discussed and compromised. There is a need of a complementary conceptualisation that helps grasping the institutionalisation process of breakthrough situations. We need to understand for instance why nano-medicine became institutionalised as a field within medicine and why nano-food, another application of nano-science and technologies, did not manage to become institutionalised within the larger field of food. For this, we build on two developments within STS and Governance studies.

The first development is associated with the notion of hybrid forum (Callon and Rip, 1992). The notion of hybrid forum links two terms that are equally important: forums as "they are open spaces where groups can come together to discuss technical options involving the collective," and hybrid as "the groups involved and the spokespersons claiming to represent them are heterogeneous, including experts, politicians, technicians and laypersons who consider themselves involved. They are also hybrid because the questions and problems taken up are addressed at different levels in a variety of domains, from ethics to economic" (Callon 2009, p. 18). Callon and his colleagues argue that hybrid forums bring together experts from three different poles (scientific, legal, socio-economic). They are places in which breakthrough innovations can be discussed, weighted, valued. Hybrid forums are not lasting and disappear when a "robust compromise" is built. But this mostly rests on principles and does not mean that the hot situation is stabilised. It is just recognized as a situation that has to be managed along specific lines.

Actors, at that point, have to act strategically to define how it can be managed. Uncertainty thus still exists. This is where the second development in Governance studies, helps understanding the effective unfolding of what we have called "market infrastructures" (Delemarle et Larédo, 2014)[12]. To address the different problems faced,

[12] Delemarle and Larédo (2014 and forthcoming) have developed the notion of market infrastructure as the set of rules, norms and values that need to exist so that a market can exist in the future. The EU

actors invest in "arenas" that correspond to their vision of the breakthrough at work, and to their analysis of what is needed to create a market. Arenas are places where "individual and collective actors interact to define the cognitive and normative dimensions of a problem" (Bonneuil et al., 2008: 205). Bonneuil and colleagues, when studying the GMO debate in France, identified 8 different arenas corresponding to different issues raised. Arenas are "issue driven", often very specific, and dedicated to produce one output that is supposed to be adopted by all stakeholders, building an agreement on one key element of the future 'market infrastructure'. Several arenas thus co-exist because actors have different visions of the problems to be solved for the market to emerge or the technology to become shared. Each arena has its own dynamics but they also interact with one another (as actors move from one arena to the other; as outputs are developed by one arena and used by others). This means that understanding the unfolding of a market or the stabilisation of a technology requires to identify the different arenas dealing with the technology/market, being able to characterise their internal dynamics (and their ability to deliver and circulate the products they aim at), being able to characterise their inter-dynamics, and their progressive convergence or alignment.

Analysing five arenas in nanotechnology Delemarle and Laredo (2014) suggest that four features are critical in the success of arenas:

(1) *The degree of specificity of the arena:* to what extent is the arena specific to an issue and to what extend it is able to treat broader subjects;
(2) *The degree of technical expertise needed to participate to the arena:* to what extent is the participation in the arena conditioned by a specifc expertise;
(3) *The degree of openness of the arena:* the openness of the arena impacts on the heterogeneity of actors. This criterion actually covers two issues. First, the openness depends on the transparency of the arena. The more transparent, the more open to new actors is the arena. Transparency relies on the existence of rules of functioning, on the formalism of the process. For instance, in the nanotechnology case studied, ISO is considered open because its processes are publicly available. On the opposite, ICoN is defined as non-open because the process through which papers are selected to be on the database is opaque. Second, the openness depends also on the existence or not of membership criteria. When no formal membership is required to participate to the arena, new actors can join more easily the arena. For instance, ISO or OECD would be considered as closed arenas because the former requires being member of a national delegation and the latter requires an invitation to formally participate to the work.
(4) *The organisational features of the arena*: in the above mentioned case study, three out of five identified arenas have developed within the boundaries of existing organisations, while the fourth one was created de novo. Two features seem to

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commission has used a plumbing comparison that is interesting to understand the notion of market infrastructure: it is a long term and costly investment; it cannot be developed by one single actor; when it is set up, we forget about it until something goes wrong.

matter here: The first is the fact that activities are eased by the existence of stabilised processes that enable to organise the work and to produce robust compromises that generate the outputs. The second important feature is the mobilisation of existing processes to shape outputs and organise their circulation. OECD WPMN and ISO TC229 illustrate this situation. Both rely on internal structures based on dedicated secretaries and standard member bodies. In the case of the nano R&D code of conduct, both aspects are missing, while the case of ICoN shows that it is not enough to have a legal form with an executive board, working groups and activities. Those that have succeeded, at least partly, also have employees, means of implementation, mechanisms to develop activities, etc. The existence of an organisation to support the arena is thus considered as an important element to consider.

2.4 A recapitulation of the conceptual building blocks we shall mobilise

To understand the emergence of a new technology, we need to complement classical scientometric / technometric analyses of cognitive dynamics by institutional analyses.

We have proposed to consider three dimensions: the visions of the future uses of the technology, the champions that promote them and the spaces in which these activities are deployed.

Contrary to scientometric / technometric analyses, institutional analyses cannot be assessed directly. An understanding of the type of institutional conditions, champions at work and spaces in which the new technology is negotiated requires qualitative analyses. These are context dependant, and in chapter three we propose to deploy approaches as ‘bricks’ (constitutive elements) that help making such contextual analyses possible.

Chapter 3 - Mobilising and tailoring tools to map breakthrough technology fields and spaces.

Chapter 3 builds on our core concept – the distinction between fields and spaces. The ambition is to articulate these in practice to follow technologies as they *de facto* emerge or, in many cases, in their attempts (often failed) to emerge. Our aim is not to provide a new theory but to build on those already existing, tailoring and adding here and there, to provide a framework that is encompassing enough to capture dynamics that take place in multiples places and are often blurred if not contradictory.

To explain the framework we propose we shall start by science, and position ourselves (as many funding agencies are) in science pushed technologies. This will enable us to move to the emergence of technology-based markets, which is becoming a more and more central issue in research and innovation policies, in particular with the drive to support the emergence of 'new technology-based firms'.
For doing so, in this section, we shall use only a few of the cases we have developed in the project, so that the reader is not lost in all the initial explanations needed about each case. We shall thus mostly use work done on nanoscience and nanotechnology and on 'additive manufacturing'. We shall also draw on our own experience with the 'field' of 'research and innovation policy studies'.

Figure 5 – Five approaches combined to map the dynamics of emerging technologies

Section 3.1 - The framework we use starts from the classical view proposed in chapter 1: science is a collective endeavour where the intrinsic distributed production requires to be validated through 'peer recognition'. Without having to enter into disciplinary aspects, scientometrics is borne from the fact that this validation goes through a dominant medium, journal articles (and key conference proceedings). Studying those we learn not only on knowledge dynamics, but also about researcher communities and ways of producing. The analysis of these virtual & material socio-cognitive networks have given rise to a full field of knowledge, scientometrics, that we mobilise here, showing that we face multiple instruments and tools for positioning an issue. Nothing is simple, as can be seen by the studies of nano S&T that some authors count in thousands articles over one decade and others in millions. But as a general phenomenon, taking scientometrics out of the "evaluation sphere" into the "positioning sphere" is a movement that is not familiar to funding agencies.[13] Without these, it seems difficult to have a permanent inquiry on the dynamics of science, and a capacity to position the numerous claims made by researchers about the prospects of the new developments they propose.

This first section will remain limited since there is ample material on these aspects. We shall use nano S&T to show the nature of problems raised since, though having fully emerged, established disciplinary categorisations do not identify it as such. This raises issues of how to delineate an emerging field. We have conducted extensive efforts in these, starting far before this project and extending now in the new European research infrastructure we coordinate (RISIS). This also requires analyses about how to identify relevant spaces for knowledge dynamics (in this case knowledge dynamics are concentrated in a few clusters that question, especially in Europe, the type of national policies developed). Within nano S&T, there are issues about internal specialisations and what types of relevant incentives it requires (we there mobilise one aspect on fields dynamics put forward in chapter one, about 'search regimes' and the approach proposed by Bonaccorsi). All of these have driven IFRIS to develop a new platform for semantic analysis (Cortext Manager),[14] which, thanks to the LaBEX SITES and the RISIS European research infrastructure project, is accessible on line for treatments.[15] As such it helps in positioning on-going developments in the field; however this does not help to grasp the institutional conditions under which this knowledge develops. Mixing fields and spaces approaches, our inquiry shows that there are three complementary dimensions to consider that we present in turn.

Section 3.2 - A first central dimension of our framework deals with the institutional conditions under which the 'want-to-be field' (from now on noted WTB field) develops – in particular the development of new journals, or how the new field is taken up in well-established ones; the creation of new conferences; the emergence of dedicated associations, learned societies mostly but also specialist consultancies (whether public private or not for profit) that produce dedicated knowledge on the field. There is no better way, we think, for illustrating the meaning of this than taking our own field, science/research and innovation policy studies. It will show how the existence of well-established journals can be disconnected from the existence of collective loci for academic discussion; and what fields need to do to build such loci, and the types of

[13] Also, to the best of our knowledge, we have not seen this capability acquired "in house".

[14] We shall also showcase some of the CorText platform usage in section 3.2.

[15] We also devote important training efforts so that it becomes an operational resource both for scholars and for analysts of public agencies.

structures that it was driven to create in order to develop both regular conferences, and processes for nurturing a shared research agenda, and even more creating dedicated tools for nurturing the renewal of the community. We draw also on a number of cases explored during the MDET project. We draw briefly on our studies of Rapid Prototyping (Robinson and Lagnau 2015) and Biofabrication (Robinson, Boon and Lagnau *forthcoming*) to show how one can analyse the content of dedicated journals and then compare with global knowledge of the fields. We shall draw on the case of Asynchronous Circuits and Systems (Delemarle 2014, Robinson et al. 2012) to describe the emergence of a society around an alternative computation regime.

Section 3.3 – Futures play a strong role in the emergence of potentially breakthrough technology fields. Since many choices remain open on which directions to take in the development, as well as the very legitimacy, of the nascent fields, visions of future worlds and supporters of such visions are necessary to build communities and coordinate for future developments. The first part focuses on promise champions – those who promote new and emerging fields of technology who mobilise visions and expectations in different ways. Promise champions create convincing expectations about the utility and value of the new field, and thus play a strong role building legitimacy and creating path dependencies, which direct the development of the field. In this section we propose four types of promise "champions" which we describe in further detail with our overarching case of nanotechnology.

Sections 3.4 & 3.5 – These sections focus on the analysis of the different spaces in which the WTB field develops, using a central notion, which we call "embedding" (Deuten et al. 1997).[16] This is the core of the new aspects we propose for building the overall framework, and dimensions that have been largely ignored and under-analysed up to now. We provide two interlinked models of embedding, one for science and one for technology.
Section 3.4 builds on the proposal by Barré et al (2013) on how to disentangle functions in a national system of innovation. Barré & colleagues distinguish between 3 layers of activities *Orientation* (macro policy framings), *Programming* (the implementation approach of policies) and *Performing* (actual research activities).
Section 3.5 focuses on the routes to embedding in markets. This techno-market translation of a technology field (which can occur in reverse as we shall show in the case of additive manufacturing) requires a number of elements to be in place to allow the identification and characterisation of routes. Here we need a new articulation of different work done and propose three levels of analysis. The first focuses on *performance* and involves finding indications of technology activity at the levels of

[16] We prefer this term to the classical term of embeddedness which mirrors a status, the result arrived at, and not the move towards the change looked for.

firms (and other innovation actors[17]). The second is on *arenas for anticipatory coordination at the industrial level* and the last is *market infrastructures* that can enable a technology to move from its niche (Rip and Kemp 1998) to the external space.

With these five sections we provide tools for mapping the dynamic of emerging breakthrough technology fields (MDET) from first signs of emergence of a field through to the moving out of the niche (a process of generalization).

3.1 – Delineation of a technology field

Summary: This first section will remain limited since there has ample discussion on these aspects elsewhere. We shall use nano S&T to show the nature of problems raised since, though having fully emerged, established disciplinary categorisations do not identify it as such. This raises issues of how to delineate an emerging field. We have conducted extensive efforts in these, starting far before this project and extending now in the new European research infrastructure we coordinate (RISIS). This also raises analyses about how to identify relevant spaces for knowledge dynamics (in this case knowledge dynamics are concentrated in a few clusters that question, especially in Europe, the type of national policies developed). Within nano S&T, there are issues about internal specialisations and what types of relevant incentives it requires (we there mobilise one aspect on fields dynamics put forward in chapter one, about 'search regimes and the approach proposed by Bonaccorsi). All these have driven IFRIS to develop a new platform for semantic analysis (Cortext Manager) which, thanks to the LaBEX SITES and the RISIS European research infrastructure project, is accessible on line for treatments. We also devote important training efforts so that it becomes an operational resource both for scholars and public agencies analysts.

In 2008 Barre et al. produced, as an output of the work done by the PRIME network of excellence, a conceptual piece about the critical importance of a new type of indicators, what they labelled 'positioning indicators'. The argument (as seen 7 years later) runs as follows: in science as in innovation, the distribution of investment and production is completely asymmetrical, few actors representing the core of efforts & production. This has been demonstrated for a long time (Lotka law) but has arrived to tremendous levels of concentration: over 50% of world industrial R&D is done by 200 'global' firms. In Europe the first 200 universities (out of nearly 4000) represent over 80% of total articles published in the WoS. Similar figures are arrived at looking at patents. Thus it becomes critical not to lose the identity of actors, which generate this knowledge: who produces it? In which organisations? Where in the world? Become important questions.

[17] There are more than firms creating innovations, even visible in our high-technology case studies we see open-source actors and hospitals as two non-traditional innovators playing a role in the generalisation of a technology to markets and to society.

For a long time we were limited in such analyses by computer capacity. For instance it was difficult to conduct semantic analyses (see the Leximappe software developed by Callon et al. in CSI) on datasets of more than 50000 items, and this after long initial times required for manual preparation of datasets. Today we work with our desk computers on samples of over 2 million items, and we can treat them on-line with newly developed semantic platforms free of access for researchers (CORTEXT manager developed in IFRIS, Paris).

This has radically changed the landscape and is transforming what had become a specialised activity (undertaking scientometric studies – not to mix with developing new tools and approaches for scientometric studies) into an element of any research programme or any 'positioning study' undertaken by adequately trained analysts (e.g, this has become part of the training of all our doctoral candidates).

Thus such approaches become a tool at the service of strategic management, in this case understanding what lies in the quest made by some researchers of the emergence of a new technology or a new field of activity for research that should be supported by funding agencies or by any performing organisation.

But for doing so, we face three initial problems:

- How to delineate the 'want to be' field/technology?
- How to enrich the datasets for future organisational and geographical approaches?
- What type of standard analyses needs to be conducted for an initial understanding of what happens in the field, what is its thematic composition? Who are the actors involved and where does it take place?

This project and report takes hold of developments conducted before and in parallel, as was mentioned from the start in the project proposal. The issue was less to develop new approaches than to test their feasibility under 'standard' conditions of use. The latter was the focus of the work done in Paris in conjunction with two other projects, one with a large firm developing tools and processes for positioning its research activities in 'targeted' specialities and organising a world level comparison; the other about the complete development of a 'demonstrator' for the analysis of an emerging field based on nanotechnology (funded before by CEA in France, and after the project by European funds, which enables to maintain the dataset over the coming years).

3.1.1 The delineation of an emerging field

In 2007 Kahane & Mogoutov produced a paper in Research Policy proposing a 'static' approach to the delineation of nanotechnology. This built upon previous work done by colleagues in Karlsruhe and in Georgia Tech[18]. This approach set the principles now

[18] Publications of methodologies are quite rare in journals such as Research Policy. They usually are linked to in-depth analysis and testing (in this case by corresponding teams in the US Department of Energy). A number of comparisons made since by successive authors looking for which method to adopt have considered that it was one of the most balanced and exhaustive (Huang et al. 2010, L'huillery et al., 2010)

adopted by most studies on new emerging fields: internal ability to build the dataset (meaning no use of external experts, that may come later once the dataset has been built); reproducibility in normal conditions of research (which for publications means working 'on line' and not with a full version of the WoS or Scopus in the lab, which is financially out of reach for nearly all teams undertaking scientometrics); stability (meaning clearly defined set of rules & procedures for others to obtain similar datasets when using the approach).
This initial approach that works in 'one round' over the whole period covered was not problematic in the early years of the emergence, but it becomes problematic when the new field starts stabilising. This is why we have used some resource of the project to define and test a 'dynamic' version of this approach (see Kahane et al., 2014, in appendix), which is now instrumented to build the new nano corpus that will be opened to all researchers in Europe under the RISIS project (end of 2015).

The approach develops in four stages:

- *Stage 1:* the definition of a core set of articles, usually with a query that uses a limited number of very specialised words that are considered specific to the field (for nanotechnology, this contained all the articles including in their title or abstract the word / prefix 'nano' – modulo exceptions, in particular nanogram or nanoliter; in fact the ability to share with other researchers has enabled to progressively enlarge this list, additions becoming de facto more an more marginal in their effect on the core dataset).

- *Stage 2:* defining the relevant vocabulary for the enlarged query. This first dataset is then 'lemmatised' and lexical analyses are conducted for defining the most relevant key words organising / structuring the dataset. This stage is rather complex, was subject to limitations (in our first development) linked to lemmatisation approaches. It has now radically changed with the availability on line of the CORTEXT manager, the outcome of a multi actor investment: the CNRS at initial exploratory stages (and in particular the development of new algorithms), INRA and the labex SITE for the 'beta version' (which in 2014 was used by more than 1000 academic researchers), and now the EC European infrastructure project RISIS for the new stabilised version to open before the end of 2015.

This provides a vocabulary. Here trade-offs have to be made about the level of specificity chosen. An initial classical solution is for a large corpus to select the first 2000 most relevant 'multi-terms'. This can be done over the whole period considered (the static approach, in our case 20 years for the last version) and for each year (the dynamic approach, enabling to track explorations made, in a static approach all that were not successful disappear). The technical choices made for building the library of relevant terms are explained in the appendix, and are now available on line with Cortext.

- *Stage 3:* testing the 'specificity' of the vocabulary in the overall publications dataset (in our case, the WoS). This is where choices have to be made that relate to 'empirical' learning to avoid too many 'false positives' (those that are not relevant) and face too many ‘false negatives’ (those we miss). We depend there on the long experience of a world level recognised specialist, Andrei Mogoutov, who, looking at previous results and the linkages between ‘core sets’ and ‘final sets’ discovered it stood in a 1 to 3 relationship. We thus have decided that at most the dataset would be made of 3 equal parts: the core set, the static extension and the dynamic extension. The selection of the static dataset is done looking at the effective specificity of each ‘multi-term’: we rank them in descending order of specificity and stop when the theoretical number of articles they generate arrives at a similar level as the core set (static dataset). We apply the same method year after year for the dynamic dataset. Interestingly we arrive for the static dataset in the 2013 version at a similar ‘specificity’ threshold than in the 2006 version: 25%. This means that we only select articles linked to ‘multi terms’, which have more than 25% of the articles identified included in the ‘core set’. The same is done for the dynamic dataset: we double year after year the core set of nano articles. And we witness that the specificity index grows year after year, from around 10% at the beginning to nearly 50% at the end of the process. This links with recent work done by Georgia Tech colleagues: they find, when extending their database over years, a trend toward a stabilisation and a growing specificity of the language used. Both trends tell that nano science might arrive to a more ‘mature’ stage, where the key alleys for further development have been identified. This does not mean a slower growth as this is not mirrored in the overall annual growth of articles: always over 10% and very near to the results of the previous analysis (14% per year between 1998 and 2006). An interesting feature lies in the very different numbers of ‘multi-terms’ relevant in the static (around 100) and the dynamic query (around 1000), showing over the period the extend of the explorations made. Further simple analyses of this vocabulary and the number of articles they generate help characterising thematic shifts over time.

- *Stage 4:* effective downloading and cleaning of the dataset. Different ‘multi terms’ can select the same article, which drives to a significant reduction in the effective dataset constructed (around 2.5 times the core set). A further analysis show how rich is the vocabulary mobilised by such an approach since on average our articles use 33 keywords selected, which strengthens the robustness of the dataset constructed.

The appendix offers a full presentation of the approach, which is presently reproduced for patents. Both datasets contain approximately 2 million entries.

An interesting development lies in comparing results arrived at for patents when either using the vocabulary built for publications or redoing the process from the start. A one-year comparison showed that 80% of words differ between both vocabularies, but that the overlap between patents selected was over 80%. This has however driven us to reproduce the approach fully for patents, for generating a dual vocabulary, both scientific and technical.

3.1.2 Organisational and institutional enrichment

Such a dataset (whether built on publications or patents) requires extensive complementary work for insuring the ability to identify relevant organisations and locations of activities developed. Many discussions are about identifying authors with the technical issues associated with homonymies and capturing their mobility between places. We consider that at a first stage of positioning, what matters are the ‘places’ and the ‘organisations’ that nurture the emergence of the WTB field/technology. Issues of individuals come at a later stage, especially if we look at recent results arrived at about mobility. One specific piece of work on nanotechnology inventors has clearly shown that the best places aggregate ‘rising stars’ (we speak of ‘prolific’ inventors when dealing with invention[19]). So positioning analyses will tell the places and organisations where competences agglomerate.

‘Place’ requires that all addresses are geolocalised and that geographical clusters are built identifying the hubs where things deploy. A first experiment before the project demonstrated the importance of the approach. It showed (Delemarle et al., 2009) that (a) we witnessed important urban concentrations (80% of articles being produced in 200 clusters worldwide of 60km circles), (b) most collaborations took place between these clusters, and, at least in Europe there were as many inter-country collaborations that intra-country collaborations, and (c) there were important hierarchies, most clusters being strongly related to a limited number of ‘core’ clusters (7 in Europe, 5 in the US). A further re-examination undertaken in 2013 was instrumental in showing the limited role of inter-continental exchanges with unexpected privileged partnerships (see Laredo & Villard, 2013).

One important implication is that it is no longer enough to conduct country comparisons to understand the conditions of emergence of new knowledge. Studying microtechnology and nanotechnology in the Grenoble area (France), Twente (The Netherlands) and other regions in Europe (Robinson, Rip and Delemarle 2015) have further reinforced in this view.

This comforted us in the need for going beyond the experimental developments made and to stabilise a suite of tools for geolocalisation, and enter into a systematic review of approaches to clustering to test and stabilise a new approach[20]. This approach is now used for the second version and being tested within the frame of RISIS. It will then be made publicly available for researchers.

All the attempts made for automatic handling of ‘organisations’ have faced very difficult situations; driving us to use our multiple ‘focalised’ projects to progressively build manually a reference dataset that we mobilise and update, project after project. Combining organisational and geographical checks, mobilising more and more Internet

[19] See the ANR project coordinated by Christian Le Bas a few years ago.

[20] This has been made available to all developers by depositing it on Github

resources, has helped us to be more and more robust. But this remains beyond the capacity and budget of any individual project. This is one of the objectives of our new European infrastructure, RISIS, to build robust reference databases or even 'registers (for universities and PROs in Europe). The combination of the efforts made by different datasets (on European projects, by ETER, on large firms) remains the best source for improving and organising this collective resource[21]. The same will happen if an agency develops such approaches: it will probably have few difficulties in handling its national situation (however we are still struggling with the French case!), but will face the investments associated with understanding other countries and their organisational features. However simple treatments show how powerful such analyses can be: they highlight the asymmetry between organisations (in the case of nano science we were for instance surprised to see that Oxford and Cambridge were playing important roles but were in no way dominating the European landscape); or we could trace the lasting importance of 'national labs' in the US, balancing the overwhelming discourse about the central (if not exclusive) role of universities, a feature even more important in fast growing Asian countries.

3.1.3 Providing first standard explorations

In order to support further reflection by field specialists and decision makers, preliminary analyses require to be made that will provide a first characterisation and profile of the field. We have combined two projects, MDET and a contract with a large firm, to build an approach and test it fully. We provide in appendix an example of the standard report we have arrived at, using solar energy research. It offers a file for publications and one for patents. Both have a similar structure. We have also developed a suite of tools for making standard inquiries on the datasets (see box 3)

Box 3. The structure of the standard file built

The publication file is in four parts.

Part 1 proposes a general characterisation around 7 points: (i) number of publications & number of addresses; (ii) thematic affiliations of publications (using standard scientific domains); (iii) time distribution of publications & addresses; (iv) spatial distribution of the same; (v) identification of 10 top countries; 5 top European and 5 top Asian; (vi) international collaborations; and (vii) spatial distribution of international collaboration

Part 2 focuses on inter-country collaborations. This is done for the whole period under consideration (often 20 years) and for different sub-periods in order to characterize transformations. For each strong relation, we give classical figures but also identify the top institutions and top authors.

[21] But multi-affiliations associated with 'mixed' labs still remain an issue to address; we also face all over Europe issues for dealing with clinical research and research hospitals.

Part 3 focuses on internal thematics based on CORTEXT. It offers a general map of clusters covering the whole period, and specific maps on sub-periods to follow transformations. A specific CORTEXT tool ("tubes") enables to follow how the themes of the general map evolve over time. For each theme we provide information on the 5 key institutions and top most cited authors. We also provide 'heat maps' enabling to position France and the top producing countries.
Part 4 is distinct form the report. It contains the dataset and enables all types of queries (under SQL lite). We have organized 2 standard set of queries: (i) for a given theme or a given pole, identify the main actors; (ii) for a given actor, identify its involvement in given themes.

The patent file is quite similar.
For thematic specialisation we use both the technological domains (most patents pertain to one technological domain) and also sub-domains (there the number is far larger and the dispersion quite high, enabling a refined characterisation). Both are used for analyzing institutional involvement. We have also developed a specific categorization of institutions so as to develop specific maps for public research, often underestimated in such analyses. A further tool has been developed to follow countries, poles and actors on the two datasets.

3.2- Field-level institutional conditions

As technology fields build up momentum, participants in this new field meet to exchange knowledge and coordinate/battle for the directions of the field. Usually dedicated conferences emerge and/or new dedicated journals (or perhaps special issues of existing journals). Identifying these can help in diagnosing the state of emergence (i.e. there are dedicated journals) but also help gather information on the content of the technology field. Other spaces* that allow for knowledge exchange and directions to be set (through strategic agenda setting and roadmapping), are dedicated associations and learned societies. These professional associations can be traced and also investigated deeper to find indications of the direction of development of a field. A third important component that provides indications of institutional conditions of the field is the existence of dedicated and specialist consultancies. These are important as they both gather details of the field and transform them into reports which become a reference point for actors involved in the emerging field (regardless of level of quality). In this section we shall describe this dimension in more detail via two cases; first we make use of our study of additive manufacturing (Robinson and Lagnau 2015) and the second case draws on our experiences internally from our own discipline, science policy studies (or more adequately phrased studies on policies for research and innovation, SPRI).

3.2.1 Learning from Additive Manufacturing

Additive Manufacturing (AM in short), this field emerged in the early 1980s with the sole focus of applications for rapid prototyping to improve and speed up new product development processes. Through the 1980s and 1990s the label "Rapid Prototyping" represented both the application focus and the technology field itself, directing the development of the tri-partite configuration of printer, material and digital design software. The production and circulation of early research took place in existing professional societies such as the International Academy of Production Engineers (CIRP), the Society of Manufacturing Engineers (SME) and the Verein der Deutschen Ingenieure (VDI). Since the early 1990s, the Wohlers Report has played a similar role in promoting and monitoring AM. Indeed, by moving around and publishing his annual industry report, Terry Wohlers has become a champion of AM, providing a repository of specialist know-how and contributing to the exchange of AM-related knowledge both within and beyond the field of rapid prototyping and tooling (RP&T) (Wohlers 2013).

By the end of the 1990s, academic researchers in the United States, Europe and Asia began to create dedicated conferences, journals, workshops and national rapid prototyping associations to discuss and advertise technological options. In 1998, members of various national rapid prototyping associations created the Global Alliance of Rapid Prototyping Associations (GARPA) "*to encourage the sharing of information on additive manufacturing*" (GARPA 2014). GARPA holds an annual summit, sponsors RP-related journals (Rapid Prototyping Journal, Virtual and Physical Prototyping, TCT Magazine) and promotes RP at industry conferences and business events.

One can explore the dedicated journals using quantitative analytical tools to explore the codified scientific knowledge as published in peer-reviewed journals. Here, we use the CorTexT Manager to build co-word and co-citation networks with the structured data re-arranged in these databases. The rationale for constructing a ***co-word map*** is to identify, link and display a string of *signal-words* shared by researchers in a scientific field. Signal-words have been conceptualized as authoritative terms that synthesize and objectify technology fields of reality. In scientific publications, authoritative terms (labelled macro-terms) are strategically organized in linked sequences to funnel the reader's interest and define problems (Callon et al., 1983). Consequently, clusters of macro-terms can give indications of problems intensely studied by researchers. ***Co-citation*** analysis can be used to "locate or compare positions, shifts, and dissonances in the disciplinary activity at different institutional or thematic levels" (Rafols et al., 2010).

Our analysis set is comprised of 824 articles published in the Rapid Prototyping Journal and Virtual and Physical Prototyping between 1995 and 2013. This dataset was chosen since both journals are central to the field of rapid prototyping with both journals being endorsed by the Global Alliance of Rapid Prototyping Associations (GARPA). Furthermore, both are referenced by Scopus, a database that provides structured bibliographic data in the form of RIS file formats, which is compatible with state of the art visualization tools.[22] We chose to visualize the co-occurrences of author keywords associated with these articles in order to identify the diversification of prominent research and development in the field of rapid prototyping research.

On the lower right hand corner of the co-occurrence network we can see the core of rapid prototyping research centered on issues linked to software and resin-based additive process technologies for applications in product development. Clustered around the upper left-hand corner we observe the diversification of research problems related to metal-based additive process technologies for applications in product manufacturing. On the upper right-hand corner of the network we find a third cluster of problems related to the use of additive process technologies for applications in medical research.

What is striking in this co-word analysis is that beyond rapid prototyping research concentrated in the three lower right-hand clusters, we distinguish two further areas of research. Research on additive process technologies and materials for manufacturing (of metals and ceramics) and tissue engineering (of bones and tissues) are two new problem areas distinct from rapid prototyping. This broadening of research directions of paths from RP is echoed in our co-citation analysis of the top 50 AM-related journals and proceedings and the top 50 AM-related cited journals and proceedings (both indexed by the Web of Science). Our heterogeneous co-citation network displays similar diversification, with new journals and proceedings situated in the life sciences clustered on the upper left and new journals and proceedings situated in materials science and applied physics on the upper right.

[22] For our visualisations, we make use of the CorTexT Manager (http://www.cortext.net/) to parse the extracted RIS files into an SQL database on which we ran a co-word analysis script called "*Map Heterogeneous Networks*".

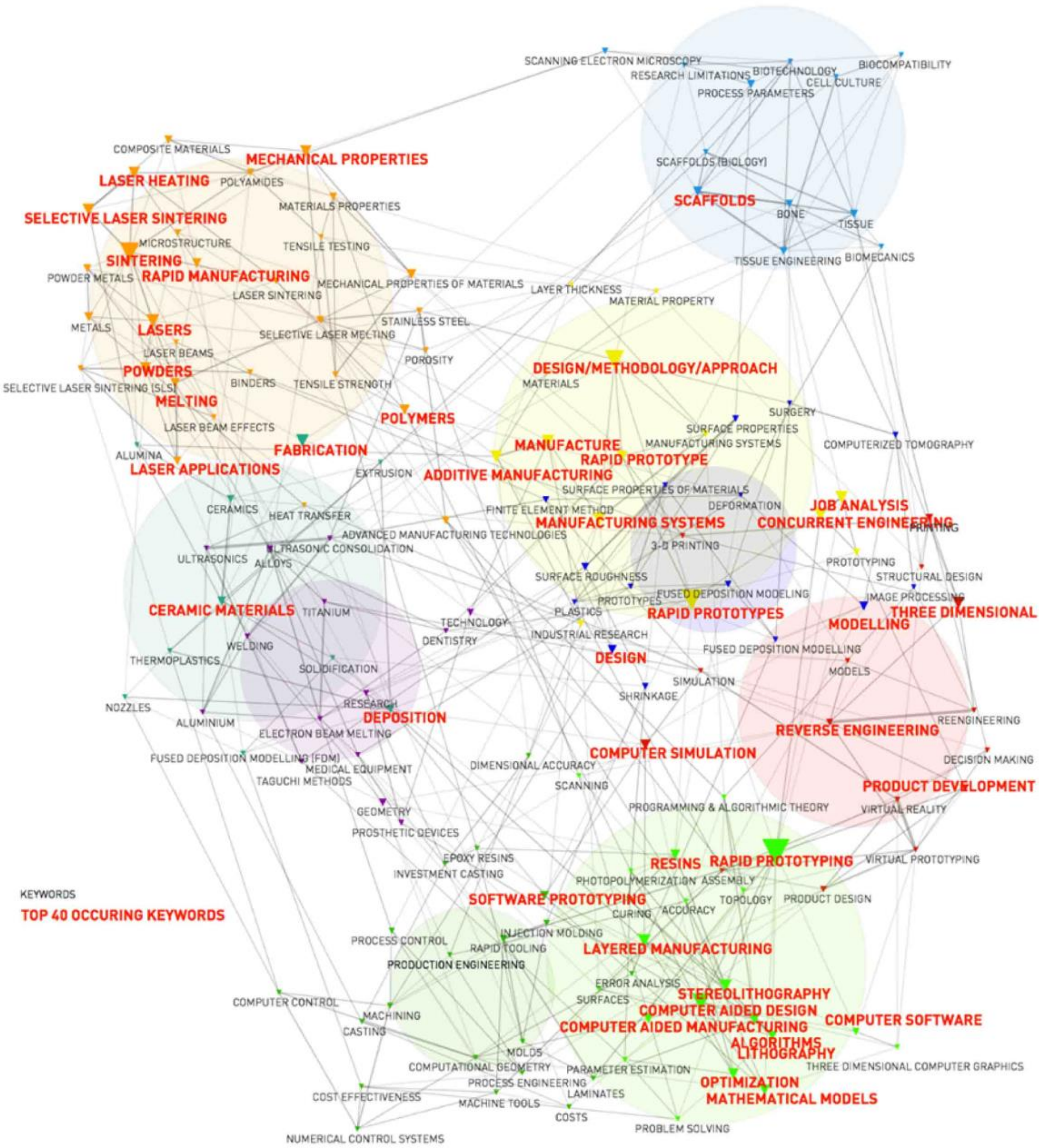

Figure 6. Co-word analysis of top 150 author keywords[23] published in the Rapid Prototyping Journals and Virtual and Physical Prototyping between 1995 and 2013 (Powered by CorTexT)
Data source. Scopus database

[23] In bold and red we chose to highlight the top 40 keywords accounting for 20% of all keyword occurrences. Concerning the choice of parameters, the network is based on a Chi 2 proximity measure between top 150 keywords with a proximity threshold of 0.2. The network was filtered to include only top 5 neighbouring nodes. Communities were detected using the Louvain community detection algorithm. The size of communities is proportional to the number of records attributed to community member nodes.

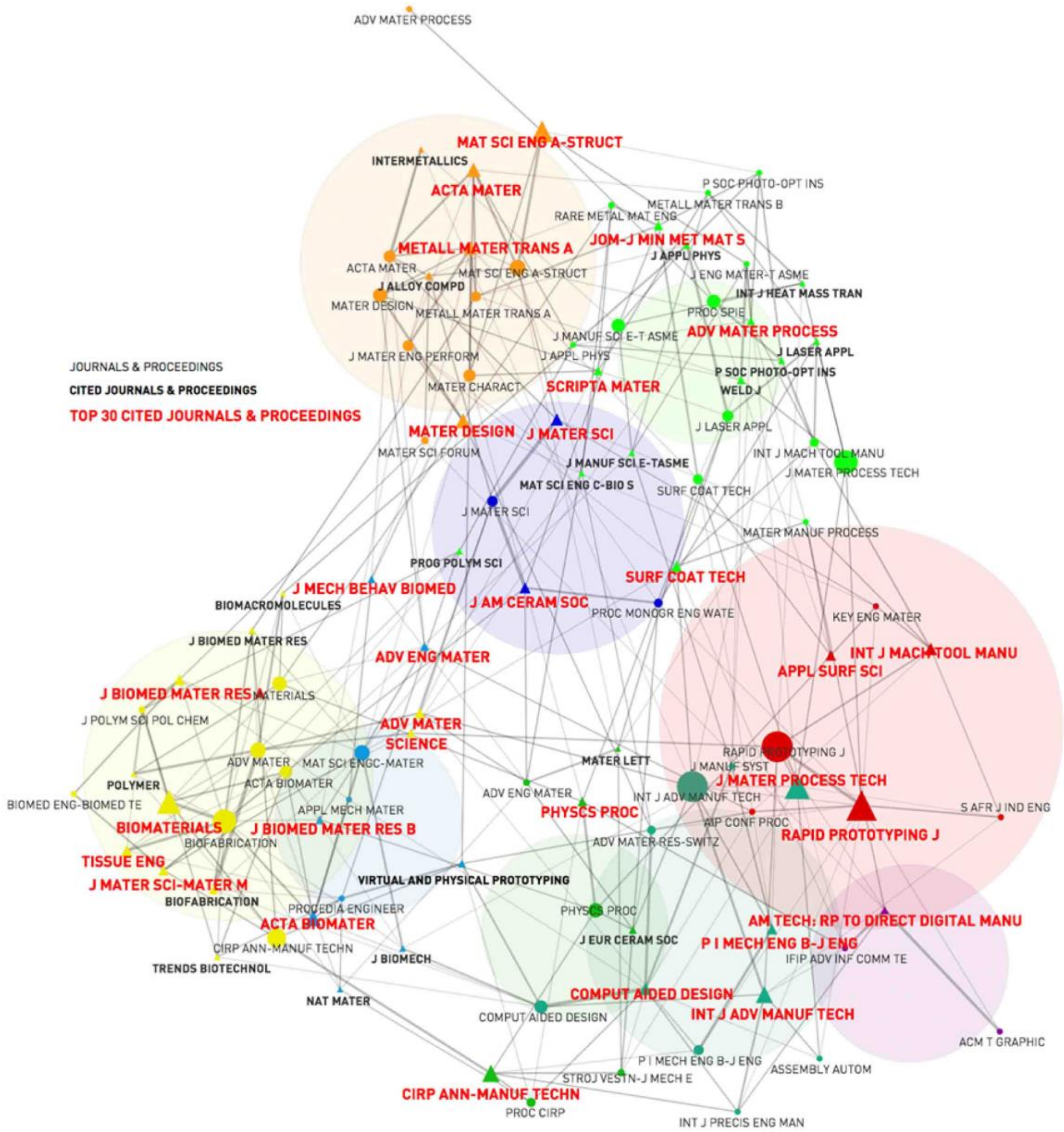

Figure 7. Co-citation analysis of top 50 journals & proceedings[24] (depicted as circles) and top 50 cited journals & proceedings (depicted as triangles) – Powered by CorText.
Data source. Web of Science database

Our second data set is comprised of 766 publications extracted from the Web of Science with the search term "additive manufacturing". We chose to visualize the journals and proceedings in which these articles are published (represented as circles) as well as the journals and proceedings they cite (represented as triangles) to characterize the knowledge base mobilized in additive manufacturing related research. Again, on the lower right hand corner of the co-citation network we can see the core of additive

[24] In bold and red we chose to highlight the top 30 cited journals and proceedings accounting for 20% of all citations. Concerning the choice of parameters, the network is based on a Chi 2 proximity measure between top 50 journals and top 50 cited journals with a proximity threshold of 0.2. The network was filtered to include only top 5 neighbouring nodes. Communities were detected using the Louvain community detection algorithm. The size of communities is proportional to the number of records attributed to community member nodes.

manufacturing research grounded in engineering knowledge. On the upper left and right hand corner a cluster of biomedical references and materials science references indicate the interdisciplinary knowledge base mobilized in additive manufacturing research.

These two analyses allows one to explore (a) the knowledge in the internal spaces of exchange (the dedicated journals approved by the association GARPA) and (b) the non-dedicated spaces (non-dedicated journals) visible in the web-of science. One can conclude that there is a diversification in terms of type of knowledge being produced (not only Rapid Prototyping, but tissue engineering and bioprinting) but also that additive manufacturing is visible in non-specialist journals.[25]

Indeed the past 10 years has seen interest and action in creating spaces for knowledge exchange and coordination. For example, the European-sponsored thematic networks such as RAPTIA (European Network Offensive for Rapid Technologies) and NEXTRAMA (Network of Excellence in Rapid Manufacturing) (WTEC 2004). As stated in a 2003 report by the World Technology Evaluation Center on AM research in the EU, this "organized effort to make advances in AM manufacturing" resulted in "levels of activity and infrastructure (…) superior to the US" (WTEC 2004). In the United States, government agencies such as the Office of Naval Research, DARPA, the Department of Energy (DOE), NASA and the National Institute of Standards (NIST) supported specialized supplier firms and researchers through the Strategic Manufacturing Initiative (STRATMAN); there were also grants from NSF and the Small Business Innovation Research program (Weber et al. 2013, Wohlers 1998, 2000, 2003, 2006). Unlike their European counterparts, American policy makers did not fund networks to stimulate collaboration. However, the DOE organized a road-mapping exercise in 1994 that was updated by the National Center for Manufacturing Science (NCMS) in 1998 (Bourell 2012). This helped specialized supplier firms coordinate efforts by identifying three directions for AM technology, namely "direct manufacturing systems", "bridge technology systems" and "design verification systems" (Bourell 2012). These temporary spaces for anticipatory coordination will be revisited in section 3.4 where we outline embedding in research and in markets.

[25] We have a dedicated case study submitted for review (Robinson and Lagnau 2015), which describes and characterises the diversification of additive manufacturing into a number of different development paths. In addition, we have zoomed into one branch, bioprinting and tissue engineering, to explore this area further (Robinson, Boon and Lagnau forthcoming). For bioprinting, a second generation of dedicated journals is visible, the Journal of Biofabrication launched in 2009, and an accompanying society (The International Society of Biofabrication). See paper for more details.

3.2.2 Learning from Studies of research and innovation policies

Additive manufacturing shows how cognitive and institutional analyses together help understanding the dynamics of an emerging field and the dual way in which scientific directions and organisational features coevolve. We shall see later by looking at the asynchronous chip design story that coevolution alone is not enough to insure embedding in economic activity, and that a new technology can become embedded as a scientific field while remaining marginal in markets. This underlines the importance of better delineating the conditions under which a specialised field (or a specialty within a wider field) can sustain over time[26].

An interesting example here is our own "field". We put field in bracket because we continue to discuss, after 45 years, whether it is a specialty or a field in its own right. The argument for the former is that it is not identified as such in classifications and thus not institutionalised as a disciplined against which researchers (as employees) are evaluated. In fact it stands at the nexus of four main established disciplines: political science, management, sociology and economics (with dimensions of geography, history and anthropology). The latter point, that it is a field in its own right, can be argued because it has its own journals, with one of them, *Research Policy*, standing as one of the best journals in all four above mentioned disciplines. They further argued that specialists were in high demand from the policymaking side, playing expert roles in most countries and at European level, thus having as a field an important societal impact. However, the evaluation conducted at the turn of the 21st century highlighted two major phenomena. First, behind the journal there no longer stood a community, rather a highly fragmented set of individual groups (if not stand alone individuals), most very small. Second there were no places for academic periodic exchange about cognitive debates, the situation of the "field", the challenges it faced and its direction. There was also the feeling that the "field" was fully taken in "normal science" with national/regional systems of innovation as a dominant design, and that most explorations were taking place at its borders under other specialties – in particular STS, evolutionary economics and governance studies. This explains why the main centres decided to take the opportunity of a new policy instrument, networks of excellence, to address these issues. The proposed network – policies for research and innovation in the move towards the ERA (PRIME) was selected. It was built on four main dimensions: (a) provide a periodic space for discussion based upon an initial agenda for the field (Laredo, 2003) and a set of review activities; (b) organise a bottom-up risk-taking process for exploring new alleys (that were not elaborated enough to enter classical funding competitions); (c) focus on the young generation through all types of activities (PhD conferences, summer schools, PhD circulation between labs)[27]; and (d) have a specific effort in reconsidering the quantitative base and corresponding indicators that support policymaking. There has been a number of evaluations of its

[26] A word of caution: the reader must accept that it is a partial view, the objective being not to provide a detailed and shared view of dynamics, but to delineate institutional conditions for sustaining the existence and dynamics of a field.

[27] Two of the authors of this report benefited from this circulation during their PhD activities.

effect, PRIME having built its own independent monitoring group (Luukonnen, 2006, for a first measure of its effects). But, the co-author of this report who was central to these developments, prefers to take three complementary markers.

The first is the will of the community to continue after the end of the five-year project. The choice was made to create an NGO based on the affiliation and financial support of academic organisations (universities and PROs), EU SPRI Forum. The second is the ability of that forum, thanks to the annual fees of its members, to maintain an annual conference (this has been the case annually since 2010), and to continue all training activities. This provides simple criteria of success: the number of institutions ready to pay an annual fee in the order of 10000 euro (17 in 2015), the number of participants to annual conferences (by and large it has doubled) and the age structure (author's personal estimates is that it has gone down 10 years over the decade, from 45 to 35 on average), the number of PhD students circulating and/or participating to EUSPRI events (maintained at the cruising level arrived at the end of PRIME). One could however discuss whether this has been as important for cognitive dynamics (and shifts). There have clearly been important enlargements in numerous aspects (governance, policy mixes or policy evaluations are some of them) but the field remains highly path dependant and this is raising strong debates as those mirrored by the last EUSPRI conference (Helsinki 2015).

And the third marker lay in our ability to turn into practice what came out from PRIME: the need to move from input-output indicators to "positioning indicators" (Lepori et al., 2008). Indicator designers were not organised and one output of PRIME was the creation of a European association of indicator designers (ENID) which main role is to organise an annual conference. One challenge was to coordinate activities with the neighbouring domain of scientometrics and its established Leiden conference, so as to reunite the two analytical arms of science dynamics. This has now been the case for over 3 years with joint conferences[28]. And one of its impacts has been the recognition by the EC of the need of a more lasting structuration, with the European research infrastructure for data supporting studies in science and innovation (RISIS, www.risis.eu) which started in 2014.

3.2.3 Discussion on institutional conditions

The reader will have understood that the analysis of SPRI is a personal view of the dynamics of a 'field'. Whether it is a fair reflection of dynamics is not what matters here. What is important lies in the institutional conditions this case highlights and that need to be taken into consideration when looking at an emerging field. We have previously mentioned the importance of academic media, journals of the field or recognition of the field in pre-existing journals. This was the case here at a very high level of academic standing. At the same time it did not prove sufficient. There needs to be a meeting place where academics and researchers can exchange about recent

[28] The key figure in scientometrics, Ton van Raan, becoming the chair of ENID

production, discuss about its articulation with societal stakeholders (in our case mostly policymakers), but also and even more anticipate about the challenges the field will face and the research directions to follow. This meeting place and its materialisation into periodic conferences is a key element of sustainability. There also needs to be processes that insure capability building with all the shared infrastructure needed when a field is emerging (meaning that the vast majority of places cannot have fully fledged PhD programmes for instance). Finally what this example shows is that is requires an organisational design at the field level: professional associations or other types of NGOs with adequate resources to organise the collective life of the field.

The case of additive manufacturing adds another key element linked to how references are built within and beyond the community, supporting its legitimation. This links with the role that specialist consultancies play at early stages. For the field of additive manufacturing, the consultancy Wohlers Associates Inc. has become the central reference point, with quotes of their annual reports predicted trends in the field being widely cited.[29] In nanotechnology, in the 2000s, Cientifica Limited and Lux Research were the consultancies whose annual reports on nanotechnology became the reference point when articulating visions of potential socio-economic impact of nanotechnology (Robinson 2009). We find similar situations in other fields, such as Lab-on-a-chip technology where the French company Yole produced, and continues to produce similar reports that are used for projections of socio-economic impacts (van Merkerk and Robinson 2006). Such consultancies promote the relevance of the field, and by producing visions of the future encapsulated in numbers, figures and graphs, help building its legitimacy for other actors and industries. In a way, they are a necessary condition for institutional entrepreneurship, which we consider a central feature of the emergence of new technology fields.

29 As an indication, the 2009 report has received 190 citations, noting that the report is annual and thus the total citations of this annual report series will be larger.

3.3- Promise champions and the role of expectations

As mentioned previously in Chapter 2: *"Future worlds are important and, when formalised, expressed in visions and expectations, drive the directions of a field. Visions need actors that 'invent', 'develop', 'circulate' and push for actions enabling their unfolding."*
Those who champion promising fields of technology mobilise visions and expectations in different ways, and all are visible when a technology field is beginning to mature. Promise champions create convincing expectations about the utility and value of the new field, and thus play a strong role building legitimacy for an emerging field. In this project we argue that there are four types of promise "champions" (Table 3) which we describe in further detail with our overarching case of nanotechnology.

Type of champion	**Role they play**	**Comments**
The Cognitive reference	The forefathers of a technology field, often referred to legitimise a field.	Usually recognised after the fact as the visionary(s) who made the initial breakthrough or invention.
Expectations pushers	These are key actors in the early growth phase of a field who develop and push expectations of the field.	Expectations pushers help to build up hype about a field which can cause "expectations niches"[30] which can be taken advantage of by institutional entrepreneurs.
Promissory organisations	These provide visions of the futures, often in the form of projected markets.	These champions may be dedicated to the field (such as Wohlers for additive manufacturing) or more generic vendors of future intelligence (such as Lux Research or the Gartner Group).
Institutional Entrepreneurs	These make use of the umbrella promise to mobilise resources and create arenas, sometimes R&D programmes sometimes physical institutions.	These champions actively forge the institutions that structure the field. One could call these institutional entrepreneurs (Garud et al. 2002)

Table 3: Four types of promise champion and the roles they play.[31]

Nanotechnology (in its broadest meaning) provides a unique case of such construction where we find the 4 types of champions, and where we can show how visions and

[30] "Expectations niches" also called "expectations envelope" are the tentative protection afforded to an emerging field fuelled by hype, hope and sunk investments (Robinson 2008). The latter is important, where even though a technology field may not be emerging rapidly, actors are less willing to give up and more to other areas if (a) hope remains that the field will emerge and (b) the need for a return on investment of resources remains low. Thus, the public sector is more willing to follow expectations for many years, whereas the private sector may employ "waiting games" (Robinson et al. 2012) or pull out all together, as was the case with lab-on-a-chip technologies (Robinson and Propp 2008).

[31] Sometimes, the same actor or organisation may play the role of more than one of these "champion functions". Distinctions are not so clear-cut, especially in real-time. For example the difference between "expectation producers" and "institutional entrepreneurs" is based around the motivation and impact of the champions.

champions are deeply interconnected. It also helps to discuss the relationship between generic and specific approaches of a WTB field. Rip and Voss (2013) have mobilised the work on semantics to speak of umbrella terms to discuss the emergence of the 'nano' category[32]. What this example shows is how 'umbrella' terms embody 'umbrella' visions and how these circulate through 'umbrella' champions.[33] It also shows that these are not instrumental at all levels. This is in particular illustrated in the inability of public debates to generate policy 'framings' for the deployment of activities: whatever the extent of discussions, it has not changed the levels of, and conditions under which, funds are allocated for research activities; similarly policy actions have not arrived at a new global regulatory framework. We shall come back to this latter point when discussing more in depth market developments (a central focus of the work done in this project, and the source of two major publications (Delemarle and Laredo 2014, Delemarle and Laredo *forthcoming*).

3.3.1 Cognitive references used to legitimise fields

Actors involved in a particular technology field often refer back to the forefathers of the emerging or stabilising field, which helps legitimise their promises. In all fields of emerging potentially breakthrough technology, broad visions of what a technology field is or could be is often attributed to a key individual, or group of individuals. These actors and their broad visions are used as a resource in making an argument for or against an emerging technology field. For, in nanotechnology, the theoretical particle physicist Richard Feynman is referred to as a founding father of the potentially breakthrough technology field labelled Nanotechnology. Richard Feynman remains a reference point as to the cognitive roots of the field of nanotechnology, with his famous lecture in 1959 (Feynman 1960), but he had little impact on the development of the field. It is important to distinguish producers of cognitive references from other types of visioning actors since their role is more of a *cognitive anchor* to the emerging field. We find similar cognitive references in many new emerging technologies. For the field of synthetic biology the foundation of the field is linked to a publication (Monod and Jacob 1961), however Craig Venter is still visible as the "institutional entrepreneur" of Synthetic Biology (Joly et al. 2012, Cameron et al. 2014). Also in another field, in Lab-on-a-chip technology, Terry (1977) is the common reference point, the first person to hypothesise that integrated micro*electronic* circuits could indeed be paralleled with integrated microfluidic circuits, to do interesting chemistry. However, it was Andreas Manz who, in the 1990s, made a first demonstration of an integrated microfluidic system and began to "*push expectations*" of what he termed as Micro-Total Analysis

[32] An "umbrella term" is a term that covers a wide-ranging subject rather than representing a specific definition. In this way umbrella terms are inherently ambiguous, can combine notions of promises, potential and on-going activities, and communities involved. Umbrella terms can become a rhetorical denominator for an emerging field – a label to refer to, which demarcates a world of research and development whilst remaining loosely defined (Robinson, Rip and Delemarle 2015).

[33] With a management perspective we can also speak of global champions that are mobilised in all spaces, as a reference for space-level visions

Systems (or MicroTAS) and enabled a community to emerge around this vision (Van Merkerk and Robinson 2006, Robinson and Propp 2008).

3.3.2 Expectation pushers

Expectation producers fuel the hype around a certain field. Their interest is to create shared interest in a field, to mobilise resources to fulfil the vision they promote. Researchers within the technology community produce expectations and share them in forums such as conferences and in journals. These "idea champions" become central when their expectations for a technology field are widely circulated and persist. That being said they may not be shared or may shift in their centrality/ legitimacy over time. This is visible in Eric Drexler, one of the key expectation pushers in the early days of nanotechnology. There have been many studies that analyse the early visions of nanotechnology and the central role Eric Drexler as an expectations pusher (Bennett and Sarewitz 2006, Berube and Shipman 2004, Rip and van Amerom 2010). In Drexler's book *Engines of Creation* (1986), he describes "molecular assemblers" as the tools that would have the capacity to construct products atom by atom, with absolute precision and without waste. In scientific circles, the feasibility of the Drexler's ideas on molecular manufacturing received very little attention, except within and around the Foresight Institute (which Drexler established in 1986). In the 1990s as more and more attention was given to advances in nanoscale materials in traditional areas of chemistry and micro-technology, exchanges between the visionaries (Drexler and others) and well known scientists such as George Whitesides (Whitesides 1998, cf. also 2001) began, including interactions at Foresight Institute conferences in 1995 and 1997. And in 1996 the first discussions of what would later become the start of the National Nanotechnology Initiative began to take shape (Roco 2004). Nanotechnology was becoming a "big thing" with increasing news coverage and an emerging national programme. However, Nobel prize winner Richard Smalley, began to question Drexler's visions of molecular assemblers on scientific grounds, leading to open out attack in an article in *Scientific American* (Smalley 2001).[34]

As Rip and van Amerom (2010) emphasize, it was clear that during the early 2000s with the attacks of Smalley, and the emergence of a National Nanotechnology Initiative: *"boundaries were being drawn as to what comprised and did not comprise nanotechnology, as well as who were "legitimate" nanotechnology players and who were not"*. During this evolution, the original Drexlerian idea of molecular manufacturing, which had been one of the guiding visions for nanotechnology (Robinson et al. 2007), were dismissed as being too "far out". Illustrative is the anecdote of Rip and van Amerom (2010) about Richard Jones, a nanoscientist and expectations pusher in the UK, who remarked at the Stanford-Paris conference on

[34] Richard Smalley argued that the manipulator fingers on Drexler's "hypothetical" self-replicating nanobot would be "too fat" to pick up and position individual atoms with precision and "too sticky" to release after having picked them up (Smalley 2001).

Social and Ethical Implications of Nano- Bio-Info Convergence (Avignon, 18-19 December 2006): "Drexler, of course, is the name that can't be spoken in polite society." "Polite society," as Rip and van Amerom point out, is the mainstream nano-world. By 2004 it was clear that Drexler was positioned on the outside of the mainstream where *"leaders in both industry and government [were] finding it easier to bring nanotechnology out of the fringe and into the mainstream, whetting the public's appetite with rudimentary commercial applications [if they] cast aside Drexler's vision, as well as his warnings"* (Berube and Shipman 2004: 24).

We thus see that Drexler was an important player in pushing expectations, building what is often labelled as an "expectations envelope"[35] raising both interest and discussions, and fuelling hype. Although Drexler created an institute (the Foresight Institute) it remained on the fringes of policy arenas, and thus did not succeed in becoming central in the promotion of nanotechnology as a policy priority, contrary to Mihail Roco who is considered as the father of the US National Nanotechnology Initiative (2000) and an archetype of our fourth type of champion, the institutional entrepreneurs (see below 3.3.4).

3.3.3. Promissory organisations

Before we need to come back to what we touched upon with additive manufacturing and the role of consultancies. They represent an important dimension of promise champions.

As well as individuals who mobilise and make use of promises to shape technology fields, consultancies and other knowledge brokers (Meyer 2010) produce and mobilise promises. Pollock and Williams (2010) analysed the activities of such consultancies. Their business is to create visions of the future that can be drawn upon as a resource (for a fee) by those involved in the technology field. Such organisations are usually not involved directly in research or development, but play a key role in shaping guiding visions of the field, enabling the mobilisation of resources (human, technical and financial) to nurture the emerging community and corresponding firms. Their role is not to produce accurate visions[36] compared to later unfolding of markets, but to produce visions that are taken up by actors as a resource for mobilizing resources and building up momentum. The authors consider these activities as a form of "promissory work".

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[35] "Expectations envelopes" also called "expectations niches" are the tentative protection afforded to an emerging field fuelled by hype, hope and sunk investments (Robinson 2008). The latter is important, where even though a technology field may not be emerging rapidly, actors are less willing to give up and more to other areas if (a) hope remains that the field will emerge and (b) the need for a return on investment of resources remains low. Thus, the public sector is more willing to follow expectations for many years, whereas the private sector may employ "waiting games" (Robinson et al. 2012) or pull out all together, as was the case with lab-on-a-chip technologies (Robinson and Propp 2008).

36 They also need not be accurate to play a role in the shaping of emerging markets, as Pollock and Williams describe in detail through their description of a representative of the Gartner group reflecting on past 'failed' anticipations.

This has driven to consider these consultancies and equivalent industrial analysts for potentially breakthrough fields as promissory organisations.
Delemarle and Laredo (2014 and 2015) enlarge the analysis to other spaces where promissory work is undertaken. Always taking the case of nanotechnology, they argue that standards setting organisations have become the place where promissory work takes place and, when successful, enables its transformation into “market infrastructures” that define the rules under which actors can anticipate, invest and shape markets. For nanotechnology, Lux Research (2004) and Cientifica (Hollister and Harper 2003) became central in producing market reports, technology trend analysis and became the reference point for nanotechnology promises in the early 2000s. Similarly, as we have seen, the Wohlers Report, written by Terry Wohlers, has been the central resource for assessing technology trends and future markets in additive manufacturing. They play a central role before markets turn effective and mature – which drive mainstream consultancies getting involved and producing their own reports and projections. This is particularly visible with additive manufacturing, the Gartner group already positioning different additive manufacturing (or 3D printing) technologies and applications in their hype-cycle diagrams (figure 8) and other consultancies such as Price Water House Coopers and Deloitte entering the additive manufacturing scene.

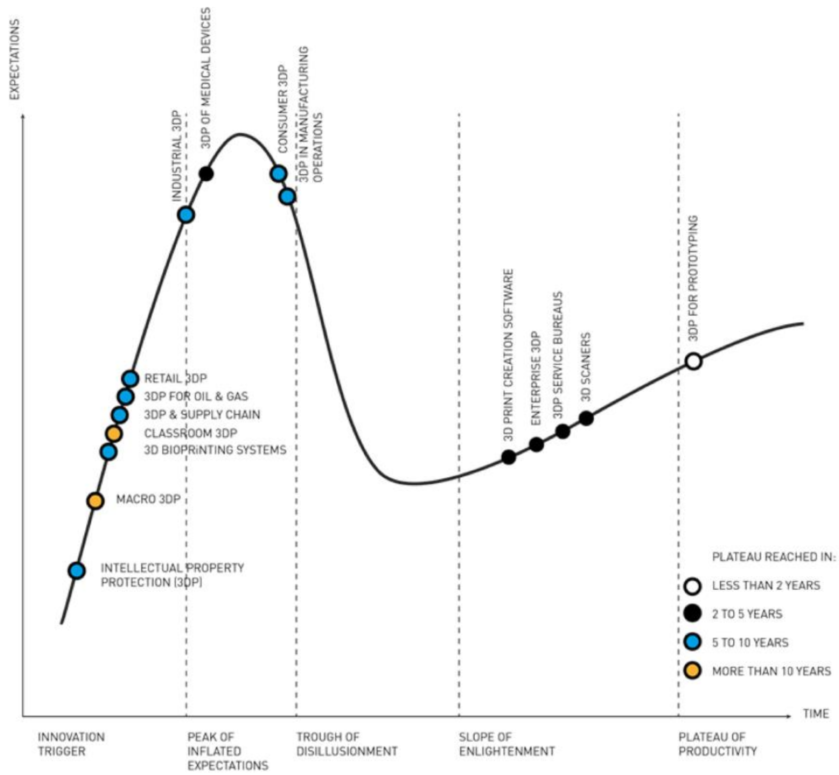

Figure 8 - Gartner 3D Printing Hype Cycle (taken from Lagnau and Robinson 2015)

3.3.4 Institutional Entrepreneurs

As in the previous example, “Nanotechnology” has remained an umbrella term, covering this variety, but it continues to be used because of the rhetorical and resource-mobilization force it has (Rip and Voss 2013). There has been, and to some extent still is, a “nano hype” (Berube 2006). This was a stimulus at the level of scientific and technology research, and led to support for further development of nanotechnology through government programmes and financial investments (a “funding race”, cf. Rip 2011).

The National Nanotechnology Initiative (NNI) is an R&D program, which was launched in October 2000 headed by Mihail Roco, and further reinforced by a law on nanotechnology R&D. It acts as a unique coordination mechanism between 20 federal departments and agencies, with an annual budget of approximately 1.5 billion US dollars.[37] Roco thus succeeded in structuring federal action in the US, through the design of what was then a very new approach, the national nanotechnology initiative, which combined political power at Presidential level, and implementation structures through leveraging the existing funding agencies and national laboratories. What is critical for the emergence of new technologies today, is that this did not only have a lasting impact in the US (the NNI budget evolved from $495 million in 2000 to $1.5 billion expected in 2015), but also and even more, had an international impact: the NNI has become a blueprint of how to organise national nanotechnology R&I policies around the globe (Larédo et al., 2010).

There has been a number of works that analyse how this could be done. What we retain from this case, is that an institutional entrepreneur is able not only to legitimate the field but embed it into lasting policies, meaning both a political discourse about their importance, and implementation structures and budgets that enable effective deployment of research activities.

Taking the same entrepreneur, Mihail Roco, and looking at his attempts to institutionalise another umbrella promise, the NBIC initiative[38], illustrates by contrast the dual need for a discourse and implementation activities. In the early 2000s, the NBIC initiative wove visions around a number of key enabling technologies and their application to improving human performance and wellbeing (Roco and Bainbridge, 2002). With projections of significant contributions to human enhancement[39] and, more recently, by promising potential solutions to societal grand challenges, NBIC have been identified by some as a cornerstone in various visions of “converging technology” (Béland, 2011; Ferarri et al., 2012). More than a decade later, there still is no agreed definition of *Converging Technology* with the term often being used interchangeably with the acronym NBIC. Also there is little link to actual R&D in converging

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[37] Source: http://nano.gov/sites/default/files/pub_resource/nni_fy15_budget_supplement.pdf

[38] NBIC is an acronym that represents the convergence of nanotechnology (N), biotechnology (B) information and communication technologies (I) and cognitive technologies (C).

[39] i.e. the technological augmentation of human capabilities and modification of the human body and intellect

technologies (Robinson 2015). However the umbrella term continues to have a life of its own and continues in the activities of *NBIC2*[40] with Mihail Roco acting as a champion.[41] *NBIC2* has broadened the original *NBIC* term that encompasses the original techno-scientific disciplines (of nano, bio, info and cognitive sciences) to include more disciplines and to consider the issues of convergence on much greater scales than research or technological development alone (OECD 2013b). And though actual developments in technology convergence remain quite separate (OECD 2014b), the involvement of Mihail Roco and its activities in various communities of exchange, continue to fuel interest in broader policy circles (as the OECD reports mentioned illustrate).

This example shows that attempts for an institutional embedding have failed and that it has driven our institutional entrepreneur facing these difficulties to adapt by deploying visualisations that reconstruct the trajectory, considering the first generation (NBIC) as passive convergence, cataloguing the present one as 'proactive' convergence, which requires an enlargement of disciplines and types of knowledge, thus the new terminology of "converging knowledge and technologies for society" (CKTS)[42] and anticipating on the new generation and its organisational requirements (see figure 9).

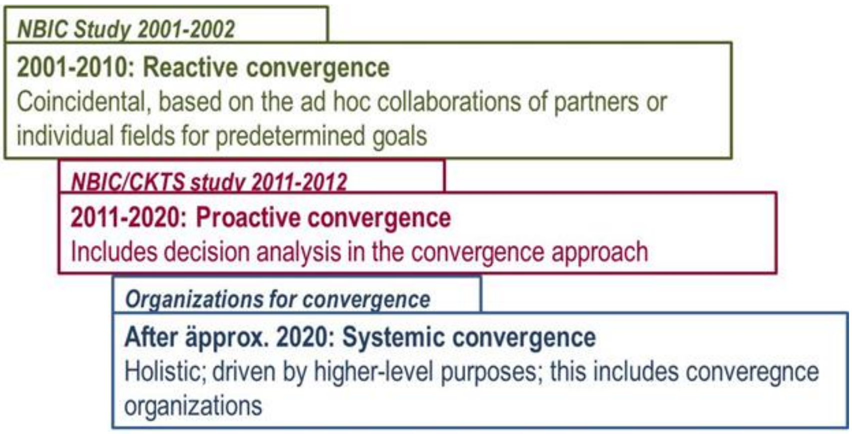

Figure 9 - Generations of the NBIC vision (adapted from Roco et al. 2013)

A regional promise champion: Jean Therme as an institutional entrepreneur

Continuing with the nanotechnology case, and looking at how promise champions shape actual activities, we focus here on one of the central results of analyses conducted, the critical role of clusters or as termed in 2007, nanodistricts (Bozeman et

[40] http://wtec.org/NBIC2/

[41] M. Roco (2012) Methods and global investments for converging technologies. Converging Technologies for Societal Benefit, Leuven, September 20, 2012.

[42] In a recent meeting, CKTS was described in terms of platforms at a variety of levels including: (1) Foundational Tools (NBIC+); (2) Earth Scale platform (Earth systems); (3) Human Scale Platforms (social-infrastructural systems such as Mega cities); and (4) Societal-Scale Platforms (how societies behave).

al., 2007) in the dynamics of nanotechnology. The argument is that, when technologies are uncertain and at the frontier, direct connections between all types all researchers and developers, in different fields of knowledge and different organisational environments are needed for new enabling technologies to have their broader impact. As they cross many disciplines, and many industries and technology chains, nanotechnologies reshape the existing organisational arrangements amongst actors, and create opportunities for new developments. Nanodistricts then enable both a technological agglomeration (Robinson et al., 2007) and they allow the creation of larger facilities, where the added value of co-location is visible for R&D as well as for developing a variety of product options – which then reinforces the strength and further development of the cluster.

The example of one successful case, Grenoble and MiNaTec[43], highlights the importance of one institutional entrepreneur in its emergence and deployment (Mangematin et al. 2006, Delemarle, 2007). The then head of CEA's LETI (*Laboratoire d'Electronique de Technologie de l'Information*) in Grenoble, Jean Therme, envisaged a central facility co-locating instrumentation and fabrication facilities from the various research centres and universities in the city, to provide a service to the various institutes, thematic programmes and industrial developments in Grenoble. He created a "flower" visualization of his vision (cf. Figure 3) showing MiNaTec as a hub for various thematic organisations and application areas. Delemarle (2007) has studied extensively the conditions of this deployment – in particular the choice of focusing on outside stakeholders rather than insiders to gain legitimacy (and the extent of the coverage made, highlighting the importance of civil society)[44] and the factory of overheads to organise and structure arguments, and to maintain coherence between the different audiences. The project was encapsulated into a flower visualisation that showed the central role of a large facility enabling to connect different actors and different sectors (see figure 2). To materialise it required important funding and new institutional frames, which are now materialised in the MiNaTec structure and facilities. The project has since gained international visibility and attractiveness and has expanded to include life sciences and medical applications of micro/nanotechnology, for example in the Clinatec facility.[45]

In this way, Jean Therme acted as an institutional entrepreneur, encapsulating the two critical dimensions of the role: (i) producing visions of the future nanodistrict with a view to co-locating technology platforms and the knowledge and networks entangled with them; and (ii) gathering the resources and developing the organisational settings able to materialize the vision and sustain the activities.

[43] www.minalogic.com (accessed 6th May 2014)

[44] This may be an important aspects in explaining how MiNaTec could overcome the harsh criticisms developed against the project in particular by the activist group PMO and its spectacular modes of opposition as well as its very organised files on what they labelled "necrotechnologies".

[45] http://www.chu-grenoble.fr/doc/Documents/clinatec%20presse%283%29.pdf

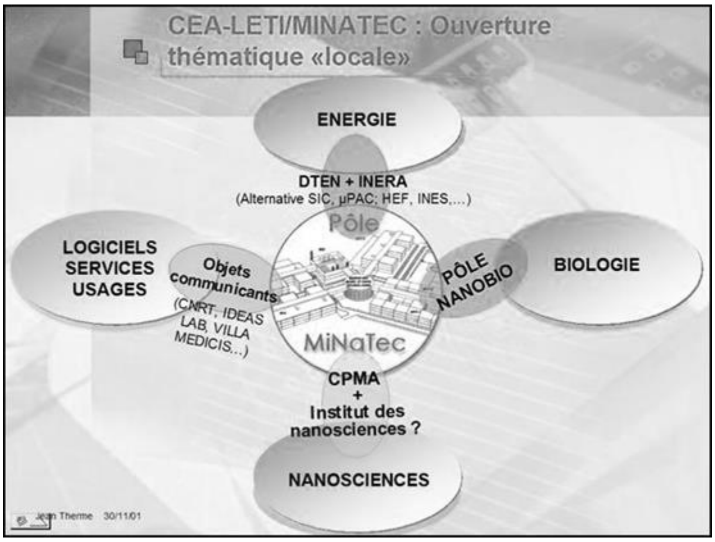

Figure 10 - Visualisation of the organising strategy for MINATEC created by Jean Therme

3.3.5 Discussion on promise champions

Our approach highlights four types of promise champions – cognitive references, expectation pushers, promissory organisations and institutional entrepreneurs. The titles link them to different activities, even if some can play more than one role. The first type emphasizes the source of any new technology, those heterodox scientists or engineers that open new avenues, or are taken retrospectively as such. The second type fuels the dynamics of the emerging technology field by proposing new visions of the technology and what it will *do* for (and change in) society. We have seen that these anticipatory capabilities are essential for attracting other actors and gaining legitimacy in targeted spheres. But we have also seen that this is not enough for action to take place; systematic structuration of information, of activities undertaken, investments made, results achieved and societal and market perspectives are an important component to bring credibility to the want to be field, and fuel resources toward it. These three components are critical resources for institutional entrepreneurs, those that shape "spaces" for activities to develop. We have used two cases in nanotechnology to show the dual dimension of institutional entrepreneurs, that is transforming the expectation into a policy discourse and priority; and organising the material and organisational conditions of their implementation: a new type of program in the case of the US federal government, a new type of structure and facility in the case of the regional MiNaTec. When these two conditions are not gathered, the promise can be maintained over time but without finding any materialisation (such as for NBIC and 'convergence').

Identifying and characterising champions for a "want to be" emerging technology is thus an important dimension of evaluating the potential for emergence. What is important and well-illustrated in the two examples of nanotechnology and additive manufacturing is that initiatives happen at the same time in different places. The ability of champions to push activities and structures in one place will have important repercussions in others: nanotechnology national initiatives have multiplied and one decade later there is no 'national research strategy' that does not make it a high level priority; The fact that nanodistricts require new types of organisational settings is widely shared. This international / global circulation of policies, institutional arrangements goes along with the circulation of priorities and agendas between funding agencies (e.g. the move toward fabrication, and the focus on application oriented research for nanotechnology programmes).

3.4. Embedding in research

This section focuses the analysis of the different spaces in which the WTB field develops, using a central notion, "embedding" (Deuten et al. 1997).[46] This is the core of the new aspects we propose for building the overall framework, and dimensions that have been largely ignored and under-analysed up to now. To develop our analytical framework, we propose to use the approach developed by Barré et al (2013) on how to disentangle functions in a national system of innovation. Barré & colleagues distinguish between 3 layers. *Performance*, as defined in classical OECD terms, remains in the model, but they distinguish two steps in the policy process between policy framing (what they call the *orientation level*) and policy implementation (the *programming function*). Their argument is that both require different competences, and have progressively driven to a separation in government administrations, a problem well recognised very early on in the OECD model (see Henriques & Laredo, 2013) but focused only then on the need for professional bureaucracies dealing with 'science'. This requirement has progressively extended and has entailed a strong movement towards the creation of dedicated agencies for the implementation of policies, what Rip has called already 30 years ago, 'implementation structures' (Rip 1990). These structures and agencies not only 'mediate', they become actors on their own and 'embedding' needs thus to be analysed at the 3 levels: of *performance* (in PROs and Universities, through positions, labs and curricula mostly), of *programming* (through the existence of funding programmes mostly) and of *orientation* (through the policy recognition of the WTB field as a 'national priority'). What makes it complex is that the situation might differ between countries, driving to different types of embedding, and different dynamics in the production of knowledge.
Our ambition here is, through illustrative cases, to show what we mean by 'embedding analyses' at each of the three levels. For analytical and presentational reasons we analyse first Embedding in research (this section) and embedding in markets (next section). As cases may be long we have chosen to put them in boxes and focus the main text on the lessons we draw.

[46] We prefer this term to the classical term of embeddedness which mirrors a status, the result arrived at, and not the move towards the change looked for.

3.4.1. Orientation level for research

Barre et al. (2013) propose, in the analysis of national systems, to separate orientation from programming functions. In order to illustrate the difference made between these functions, we shall use old STS work dealing with translation processes (Larédo et al., 1992). Using diabetes research we show the difference between the 'stake' (a socio-economical problem to be resolved, e.g. curing insulin B dependent patients), the 'goal' (the approach selected which translates a certain understanding of the problem, in this case choosing a transplantation technique, and transplanting B cells), the 'objectives' (the scientific and technical choices which are made, here extract purified B cells from human pancreases, and not for instance cultivate them) and the 'expected end results' (implanted purified B cells in insulin dependent patients). This translation process also renders explicit the durable arrangements that accompany the scientific activities: the logistical organisation of the circulation of pancreases, the purification techniques and the implantation techniques (with corresponding facilities, equipment and competences)[47]. We see that at each translation step we enter in a greater degree of precision often driving to aspects highlighted by innovation studies: 'irreversible' choices and potential lock-in situations. Our contention here is that the orientation level is mostly situated at the level of 'stakes' while sometimes entering into this of 'goals'. The example below is taken from the 2009 French national strategy for research and innovation[48]. We clearly see the general nature of the statement produced, that could apply de facto to any country: the country has advantages and it should pull its forces to enable developments in nano-electronics, nanomaterials and nano-biotechnologies which constitute the 3 main branches of nanotechnology research. It should deepen 3 transversal competences: nanofabrication & nano-characterisation, multi-scale modelling, risk and safety management. All this just corresponds to a standard description of all nanotechnology priority issues analysed. However we move to the level of goals when the text says that it should be implemented in a "nanoinnov" programme and should focus on the two poles of Grenoble and Paris-Saclay.

It is not an issue to say the expression is 'banal', but rather that orientations remain at a very general level. Their role is to fuel legitimation and to enable budgetary allocations at a higher level, as has been the case with the US National Nanotechnology Initiative included in the 2001 budget and further confirmed in 2003 by the US 21st century nanotechnology R&D act. They represent important landmarks as they enable to identify spaces for which the emerging technology is taken seriously and officially established as a priority. But to understand what happens de facto, what are the efforts made, and how the emerging technology develops, one need to enter into the 'programming level'.

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[47] Following intermediary results becomes then an important tool for testing the robustness of the translation proposed and the eventual need for adaptation or in the case mentioned complete revision. This links with the work done in strategic management on the role of narration and narratives. Kahane (2005) using similar examples has proposed the notion of 'narraction' to embed the link between discourse and action.

[48] A new one, dealing only with research, has been produced in 2014.

Box 4: Nanotechnology in the French National strategy for research and innovation (2009)

Source: Ministère de l'enseignement supérieur et de la recherche, Strategie nationale de la recherché et de l'innovation, rapport final, 2009, 42 p.

Résumé (p. 9) : réussir la révolution des nanotechnologies, dans les domaines de l'électronique, des matériaux et des technologies pour la santé aussi bien que dans celui des énergies renouvelables.

Texte complet (P. 39) : Développer de manière responsable les nanotechnologies en France
Nanosciences et nanotechnologies sont indissociables pour le développement des matériaux du futur. La France possède des atouts indéniables dans ces domaines et tant l'intérêt fondamental que les enjeux technologiques associés justifient le regroupement des forces sur le plan national et une collaboration active entre physiciens, chimistes et biologistes, ainsi qu'entre concepteurs, fabricants et utilisateurs. Une telle mise en commun des forces est essentielle pour explorer et développer en particulier trois domaines :

• la nanoélectronique ouvre de nouvelles perspectives scientifiques à partir d'effets physiques non exploités jusqu'à récemment (électronique quantique, électronique moléculaire, spintronique, nano-photonique, …). De nouvelles opportunités en résultent, technologiques (électronique basse consommation) et applicatives (systèmes sur puce, objets communicants)
• les nanomatériaux et matériaux structurés à l'échelle nanométrique, présentent des propriétés nouvelles, liées à la taille ou à l'organisation (nanotubes de carbone, fullerènes)
• les nano-biotechnologies, à la jonction entre le monde du vivant et de l'inerte, ouvrent la voie à de nombreuses possibilités d'applications, en particulier en biologie, en médecine et en agro-alimentaire.

Les trois domaines s'appuient sur trois compétences transverses essentielles : la nano-fabrication et la nano-caractérisation ; la modélisation multi-échelle et multi-physique ; la sécurité et la gestion des risques autour des nanomatériaux.
Le projet « NanoInnov » doit positionner la France au premier plan de la compétition internationale dans ce domaine, notamment autour du pôle de Saclay en lien avec celui de Grenoble. Ce projet devra également s'inscrire dans une dynamique européenne au travers de l'IET.

3.4.2. Programming level for research

Barre et al. (2013) contend that the programming level – the ways in which broad brushed orientations as those found in national strategies, are operationalized, and resources allocated – is becoming more and more important in research and innovation policies. This follows the work by Rip and colleagues in the 1990s on national research systems in transition, highlighting the growing role of the 'intermediate layer'. How then to grasp situations?
A first dimension deals with the major channels of resource allocation. The classical way was to consider two exclusive paths: dedicated PROs (with professional researchers) and funding agencies (supporting research in universities). De facto both have always been mixed, though the mix has changed over time. A good example is Germany with the consolidation of public research in two very large "not for profit societies" (the Helmholtz society and the Leibniz society) complementing the two large

pre-existing ones, the Max Planck society and the Fraunhofer society. This very large public sector is complemented by a powerful funding agency (DFG). Most countries have now similar mixes. This means that when looking at how the programming level engages in supporting a new field, simply looking at project-based funding programmes might be misleading. One would have difficulty in understanding the US nanotechnology landscape without taking into account the critical role of 'national laboratories' in building the research infrastructure, having in a way much in common with how CEA and CNRS in France have organised their platforms.

The classical level of observation of the 'institutionalisation' of a want to be technology is to consider the existence of public targeted funding programmes: is there a country, a state or a region that recognises it as a priority and channels funds toward research in this field? We of course tend to look at the US and its agencies (NSF but even more the research efforts of the departments of defence and energy – in particular DARPA and EARPA, see Laredo 2014 for an analysis of their role in 'frontier research'). Public programmes offer a rich source of information: they all produce argumentations about the importance of the emerging technology and the visions of the future it promotes; they have a budget which enables to measure the relative importance given to the new potential field; they define research agendas enabling to have a view of research directions; and they fund actors and projects, which enable at a finer level of analysis to understand how research directions are implemented and who are the key actors. This applies well for large new priorities such as our central example, nanotechnology; however we have studied two cases of development within the project that have developed on the ground of opportunities created by 'wider' programmes or funding sources that never mentioned the technology once in their priorities or work programmes: in Europe the OMI programme and asynchronous chip design, and more recently 'rapid prototyping and 3D printing'.

But there are not only Governmental programmes or programmes run by public authorities (like regions or cities), "civil society organisations" become more and more active and can play a role, providing resources for programming and operating project-based allocation of funding. Callon & Rabeharisoa have studied the role that patient associations have played in France for legitimising orphan diseases, for supporting and even rearranging research around these issues, as is well illustrated by the actions of AFM. This example also shows that such CSOs can even become important performing actors (as AFM with Genethon). And one of the largest funding organisations for health research worldwide is now the Bill and Melinda Gates foundation.

It is not enough to consider 'implementation structures' and their programming activities. The type of delegation and the channels through which they operate plays an important role in shaping research activities. In this report (see box 5), following on our nanotechnology focus, we show how in the Dutch case a bottom-up process initially started by one university in one cluster has transformed into the construction of a country-level association of universities and PROs investing in nanotechnology negotiating with the government a national programme, NanoNed, which they manage.

This delegation seems sustainable as they enter now in the next programme version: NanoNext NL.

The role of implementation structures is further illustrated by the own experience of one of the co-authors of this report. As the president of the orientation committee of the nanotechnology programme within ANR, he pushed with his fellow members for more 'fundamental research' deepening the understanding of phenomena. The idea was that the work conducted in academic labs would have 'industry' gatekeepers following it and introducing it to their firms. It took nearly three years to become a quasi-systematic feature of this type of projects. A decision was then made at higher levels (of the organisation) to completely regroup support to fundamental research in a fully bottom-up process, and, if a nano orientation was kept, it completely destroyed the connections built over time. The action moved, to follow Rip (1986) from orchestration to accommodation, where in the former the action pushed for a change of behaviour, while in the latter the action simply accompanies what researchers propose: no wonder that the linkages were broken in one year!

Box 5. Organising the programming level: The Dutch national nanotechnology initiative.

In the Netherlands, the national nanotechnology programme (NanoNed) emerged at the programming level through the concertation and coordination between a number of institutional entrepreneurs located at technical universities who, to maintain growth at the local level, banded together to stimulate regional growth and investment in nanotechnology. .

The programme originated in teams from the University of Twente working in the general area of sensors, actuators and micro-systems. By 1999, further mergers with electronics, optics, and materials research groups led to the establishment of a new institute, MESA+, with important investments in clean room facilities and linked to a Techno Park (itself building on predecessors from the early 1990s). MESA+ has acquired since high international visibility and is embedded in networks of excellence.

This gradual convergence and the eventual uptake of the label 'nanotechnology' had much to do with the availability of overlapping technology platforms and the possibility of their expansion – which required institutional entrepreneurship. Instead of attempting to expand and consolidate MESA+, which might have been problematic because of the small size of the university and the region, and the limited infrastructure (at the time, no major companies with an interest in nanotechnology were involved), the 'band of four' - David Reinhoudt and his fellow entrepreneurs, the business director of MESA+ and two regional actors – decided to pursue two tracks. One focused on start-ups and support for creating value and mobilizing resources from relevant actors, including the national-level Ministry of Economic Affairs. The other focused on the possibility of developing a national-level priority for nano-science & technology. To be credible in pursuing this second track involved joining forces with the two other big centres in the Netherlands, BIOMADE (University of Groningen) and DIMES (Technical University of Delft). This action relates to a Royal Netherlands Academy of Science's policy of support for nano-science & technology, which had itself been prepared by the directors of the three centres. This dual-track approach highlights two interesting features:

- how regional cluster-building might require alliances with centres elsewhere,
- how a multi-level situation allows positive feedback, i.e. preparing the ground at the national level, for subsequent institutional entrepreneurship.

In 2000, the three nanotech centres developed a "Masterplan Nanotechnology", following advice from the government Ministry of Economic Affairs, which also suggested funding possibilities. At the same time (2000) the Ministry of Economic Affairs was considering which themes should be highlighted in preparing for the third round of the ICES/KIS funding program for supporting knowledge infrastructure. At first, nanotechnology was included under ICT, but advisers suggested it should be a separate theme (perhaps combined with micro-systems). The alliance of the three centres would be an obvious candidate to bid for this theme, even though it was more application-oriented than nanoscience and technology could be at the time. The Ministry – via an active senior official who was something of a bureaucratic entrepreneur – made it clear informally to the alliance that it was prepared to exert political pressure to include nanotechnology. The cluster-building aspirations of the Twente 'band of four' now became secondary to the attempt to access ICES-KIS funding. This shift was reinforced when other actors (TNO, the big applied-research organisation in the Netherlands, and the Technical University of Eindhoven) claimed they should have access to ICES-KIS nanotechnology funding as well. The Ministry of Economic Affairs accepted these claims and asked two consultants to check the quality and infrastructural capabilities of the various competitors. Their work (May-July 2001) was the starting point in the assembly of a consortium, which eventually had eight partners, rather than just three centres. In other words, the building of a Twente cluster was temporarily superseded by the attempt to secure ICES-KIS funding. The net effect was of stronger interactions at the national level, creating, in effect, one thematic cluster (with an internal division of labour amongst the actors) at the national level (the Netherlands is a small country!).

The Expression of Interest for the ICES-KIS call was written and submitted in August 2001. The Ministry, through its entrepreneurial senior official, continued its support by making special funding (Nano-Impulse, part of an Innovation Impulse funding programme) available to maintain momentum while the full proposal was written up for the March 2003 deadline. An effect was the need to achieve some semblance of coordination between partners who otherwise might see themselves in outright competition. Cluster participants were positioned according to their specializations with cross-cutting "flagships" at the consortium national level.

In conclusion, the situation of nanotechnology in the Netherlands is interesting because it shows that *programme-level* activities were delegated to the nanotechnology consortium, who became responsible for nanotechnology R&D coordination at the national level, and where the consortium would report to the government on a regular basis. The consortium continues to play this role today as NanoNextNL.

We thus propose four major entry points for looking at forms and degrees of institutionalisation at the 'programming level'. The *first one* deals with the respective roles of project-based funding agencies and of PROs: are the latter taken as any other performing entity, or are they given a specific role parallel to this of funding agencies (for instance in term of facility building)? The *second one* deals with the existence of dedicated funding programmes, their location, their absolute and relative importance, their research agendas and their activities. The *third one* is to consider the existence of CSOs that play a role in shaping agendas and legitimising the WBT field, provide resources and sometimes engage in performing activities. And the *last one* deals with the processes put in action to organise action and channel funds. A recent report highlights the importance of the portfolio of instruments mobilised and their interactions, what is now labelled 'policy mixes' (Cunningham et al., 2012).

3.4.3. Local Embedding in research

Probably the least studied dimension deals with local embedding: how the WTB field is recognised by the employing institutions of researchers as a relevant field, how does this translate in their positions, in the construction of labs, and in the construction of teaching curriculum. This represents a major issue when discussing capability building and possibilities for researchers to aggregate resources beyond and above the search for grants and contracts.

Our surprise was that we could not find any work dealing with these aspects and proposing an approach. Thus we have devised one, presented and discussed in a number of conferences. We have tested it on asynchronous chip design and applied it to the field of rapid prototyping/ additive manufacturing. We have heavily invested in the project (Robinson and Lagnau 2015) to understand the dynamics of this very unusual field. We apply the approach to show that, while there were has been little recognition at the policy level for the first 20 years of the field, and no effort at the programming level, individual universities have recognised researchers, created labs and invested in structuring resources around them.

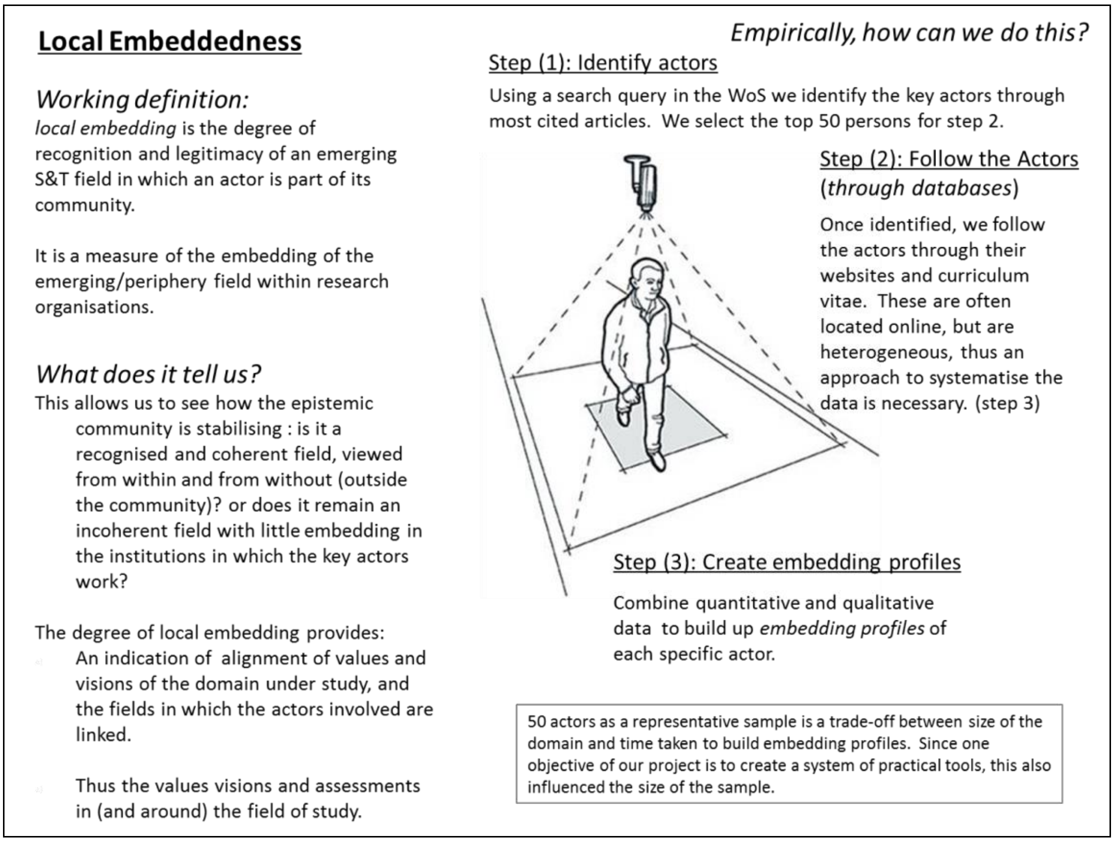

Figure 11: The process of local embedding (Robinson et al. 2012)

The figure above, taken from one presentation, summarises the rationale and objectives for studying local embedding. An actor that participates in conferences or journals of the WTB field, is herself part of an organisation where she draws a salary and has a career path. Understanding how this actor is inserted in his institution, his status, the

existence of research structures and/or curriculum dealing with the field, the inscription of the field into the key topics of the university, etc. are markers of the ability of the actor to dedicate herself to the field and of the resources she is able to gather. This analysis is particularly important to assess the positioning of the new field within the host organisations of the key actors of the breakthrough technology community.
Local embedding is thus a measure of local recognition, and legitimacy, of the focal emerging technology field in an institution/organisation, e.g. the degree of local embedding of additive manufacturing technology in a metal manufacturing research institute. Looking at the "degree of local embedding" provides an indication of how accepted the new field is within given spaces.

Empirically, how can we do this?

Step (1): Identify actors:	Using a search query in the WoS we identify the key actors through most cited articles. (A good trade-off here is to choose the top 30 or 50 persons for step 2.)
Step (2): Follow the Actors (through databases)	Once identified, we follow the actors through their websites and curriculum vitae. These are often located online, but are heterogeneous, thus an approach to systematise the data is necessary. (step 3)
Step (3): Create embedding profiles	Combine quantitative and qualitative data to build up embedding profiles of each specific actor.

What is an embedding profile?

For each actor identified we create a *local embedding profile*, which provides an indication of the importance/relevance placed on additive manufacturing within their home institution. Aside from personal data, we have four themes for the embedding profile within the home institution (locations of such data is given in the table later):

- *Research Group:* Do they have a research group where the new field is specifically mentioned? If on the institutional webpage they are in, or lead, a research group dedicated to this breakthrough area (for example in asynchronous design). Such information provides and indication that the group is well embedded. Useful also is the age of the group.
- *Research Track:* Do they have a research group where the breakthrough technology field is specifically mentioned?
- *Education:* Are there courses dedicated to training in the breakthrough field? This shows the relevance/importance of the field in the training of engineers
- *Industry Links:* Are companies involved in the groups working on asynchronous design? Sponsors of the lab, collaborators or do they have interns from these labs in their companies?

This approach enabled us to build datasets along these dimensions and short profiles that helped us understand the paradoxical situation of additive manufacturing: strongly embedded in a number of universities while not considered at programming levels (box 6). It also gave an explanation of the inability of asynchronous chip design to gain momentum as most key researchers are now inserted in broader themes as one element among others, often not even visible as such (box 7).

Box 6. Local embedding example from additive manufacturing

In this example, we ran a query on additive manufacturing through the Web of Science and identified the top publishing authors in the UK (because we were interested in embedding in the UK). We identified a number of authors but have chosen Prof. Richard Hague of the University of Nottingham, as our small example. Richard Hague was co-organiser of the 9th Additive Manufacturing conference in 2014 at the University of Nottingham where two of the authors of this report attended.

Richard Hague is one of the spokespersons of the advanced engineering path of development in additive manufacturing (see Robinson and Lagnau 2015). When you explore his institutional webpage and annual reports of the University of Nottingham, one can find that Richard Hague is the Director of the EPSRC Centre for Innovative Manufacturing in Additive Manufacturing at the University of Nottingham. His group conducts a large portfolio of projects (the current portfolio of research funding totals more than 10 million pounds) on a large number of areas relevant for the field of additive manufacturing such as printing processes, digital modelling, materials research and process optimisation. Professor Hague also coordinates, with his colleagues at the University of Nottingham, a pan-UK PhD training programme (launched in October 2014). Also visible in his research groups website is that there are strong ties to industry through the organised structuring of PhD funding combining public agency and Industrial actor financing.

This example is interesting because it shows the state of the Additive manufacturing through the lens of *dedicated* training of researchers in this area. It also shows the relevance of additive manufacturing in the University of Nottingham (very high, because of large scale investment in machinery and the laboratory). It is important to point out that this year sees the 10th annual meeting, with Professor Hague being involved since the first meeting long before there was any orientation level or programming level activity in the UK.

Box 7. Local embedding example from asynchronous circuits and systems

In this example, we ran a query on asynchronous design of circuits and systems through the Web of Science. By identifying the authors who had the most publications over the past 10 years, we selected the top 50 and started creating embedding profiles. Here we present Jens Sparso as an example. Prof. Sparso is a Danish researcher in the top 50 publishing authors, and chair of the ASYNC IEEE conference that was held in 2012 in Denmark, and which the authors of this report participated and ran a roundtable (Robinson et al 2012).

By going to his institutional homepage, we were able to construct an embedding profile and to explore his local situation more broadly. What is clear when one looks at this profile, although Prof. Sparso is a key player in the Asynchronous community, asynchronous design of integrated circuits is only part of the activity of Prof. Sparso. It is in a list of a foci on what is now known as Networks-on-a-chip and Systems-on-a-chip technology (see figure 14 later). At his host institution there are limited dedicated courses on asynchronous design, though Prof. Sparso is the author of the key textbook on asynchronous design.

What does this brief example tell us? It tells us that asynchronous logic is not well embedded in the local institution, but survives as part of another technology path of systems-on-a-chip and networks on a chip. Indeed in the ASYNC 2012 meeting we referred to earlier, it was collocated with another conference on networks-on-a-chip. These kinds of details, of the top publishing authors, are useful in gauging the degree of local embedment. It can also be triangulated with other embedding indicators such as being part of the anticipatory coordination activities such as ITRS etc.

In this section we have seen three levels of institutional embedding dealing with one country / space. Orientation level tells about higher-level consideration of the issue. The NNI case shows it might have important implications not only at home but even more in other countries, through mimetic behaviours. We have put more emphasis to understand dynamics of institutional embedding in the two other levels. We propose four aspects to look at the programming level: the respective roles of funding agencies and PROs; the existence and consistency of project-based funding programmes; the existence and activities of Civil Society Organisations (CSOs) in programming; and the policy-mix of funding bodies. We consider they help characterise how public / collective policy deploys in order to support and promote (or not) the emerging field. But we have been surprised to see how little was done to understand ‘local embedding’, that is how performing organisations recognise and support capability building (in training and research) in the emerging field. The ‘stronger’ the organisations (as is the objective of the 2020 vision of the European Union), the greater their role will be in emerging science and technologies, driving to a distributed capability of deployment (facing the traditional top-down view of the dominating roles of policies and funding agencies).

3.5. Embedding in markets

One of the key lessons we derive from our case studies confirm that the process that drives 'impacts in society' requires complete reconsideration. Not only because it is not a linear model (the classical discourse) and is iterative, but even more because very often first market entries in niches cannot tell the future of the technology. If it had been so, then today chips following the asynchronous chip design would be in the billions while today, they are nearly nowhere to be seen. This has prompted us to recognise the importance of 'protected spaces' and 'niches' (Rip and Kemp, 1998) both for early design and testing of the technology, but also for initial market introduction of new products embodying the new technology (Geels, 2002). But it has also driven us to questions about the collective conditions that help the products that embed the new technology get out of their niches and widely 'diffuse' (Rogers, 1961, 2003) and generalise (see Collinet et al., 2013 for a review). We shall take into account, in this section, the developments we have made to address this latter aspect, which we do be mobilising the notion of 'market infrastructures'. Furthermore, these reflections have triggered us to consider that 'early commercialisation' should be approached with care, one should be cautious about what is actually happening and how it is evolving – perhaps indications show that there is just a growing interest in the field and increasing promises of potential value. Thus it does not systematically signal that we enter in a maturing phase, rather it remains often part of the dynamics of emergence. We shall see that the diffusion of 'rapid prototyping machines' is rather a starting point to new developments in different application areas, as the analysis of branching paths suggests. Similarly while we already speak of 'nanotechnology products' (there are even NGOs that list them), we witness no generalisation, and even "waiting games" on the side of large firms.

How then to get a better handle on a situation where there are already 'market' aspects visible. We propose, following developments in chapter 2, to keep the approach of Barre, adapting the three functions to 'innovation paths'. The first level remains as *performance* and involves finding indications of technology activity at the levels of firms (and other innovation actors[49]). The second is on *arenas for anticipatory coordination at the industrial level* and the last is *market infrastructures* that can enable a technology to move from its niche to the external space.

[49] There are more than firms creating innovations, even visible in our high-technology case studies we see open-source actors and hospitals as two non-traditional innovators playing a role in the generalisation of a technology to markets and to society.

3.5.1. Measuring performance in the embedding of technology into markets

Performance in terms of emerging industries and the embedding in markets draws on descriptors, markers and indicators[50], such as number of firms and types of firms (supplier firms, service providers etc.), key patents and the patent landscape, firm entries, firm exits, IPOs and mergers and acquisitions. Here we draw once again on our case study of Additive Manufacturing to investigate how to observe performance in terms of the emergence of an industry and the extent and form of embedding in markets. Our ambition, through the story, is to show the visualisations proposed that enable having synthetic views of on-going developments.

The beginning of the move from the world of research towards embedding in markets of additive manufacturing (then labelled rapid prototyping) began quite early in the emergence of the field with the first key patents. In the 1980s, advances in computing, computer-aided design, lasers, printing technology, programmable logic controllers (PLCs), and materials enabled the development of functional additive manufacturing systems (Gibson et al., 2010). In the 1990s, new specialized supplier firms such as 3D Systems, Stratasys, EOS GmbH, D-MEC and CMET commercialized various systems based upon exclusive patents. Incumbent firms such as Ciba-Geigy (now Huntsman), DSM (Somos) and JSR Corporation provided a limited range of materials for mainly plastic-based additive manufacturing printers (Wohlers, 2013a). STL, a generic 3D file format to use for the designs that could be "printed" with additive manufacturing, was developed by 3D Systems and made freely available to "*allow CAD vendors to access it easily and hopefully integrate it into their systems*" (Gibson et al., 2010).

STL quickly became a *de facto* standard among professional additive manufacturing users (Jurrens, 1999). These early users included industrial designers, which were the first to use additive manufacturing to produce concept models and functional prototypes. Compared to established methods, early machines significantly improved the speed and reduced the cost of product development cycles and came to be known as rapid prototyping (RP) (Bernard and Fischer, 2002; Bernard and Taillandier, 1998). Rapid Prototyping became the prime vision of utility to improve new product development processes through rapid prototyping.

Beyond industrial design, the promise of rapid prototyping generated interest among medical professionals. Dentists and surgeons used additive manufacturing machines to make patient-specific models and tools such as surgical guides. Architects and artists also applied additive manufacturing to produce architectural models and "*digital sculptures*". By the late 1990s, AM was applied to make long-term consistency tools (Cheah et al., 2005; Karapatis et al., 1998) capable of producing "*thousands or even millions of parts before final wear-out*" (Levy et al., 2003).

To explore the performance of additive manufacturing over time, we make use of two composite graphs. The first shows descriptors and markers concerning firms, the second for patents.

[50] We use here the categories proposed by Reale, Lepori et al. (2013).

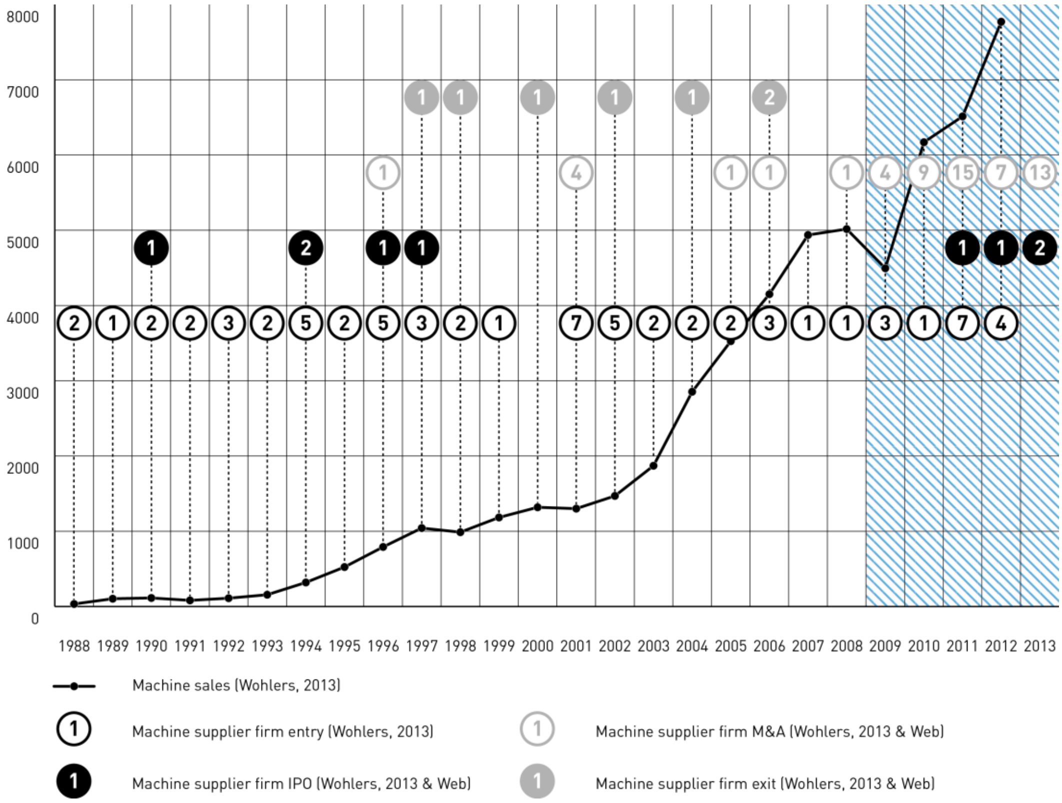

Figure 12: The growth in number of machine supplier firms overlaid on yearly machine sales
Source: Robinson and Lagnau (2015)

Figure xx follows the additive manufacturing machines sales. There is almost consistent growth in sales since the early 1990s with a dip following the global financial crisis of 2008. What is interesting here is there are two phases visible. The first phase sees a burst in supplier firms including a number of IPOs. This period is followed by a period of firm exits, some further firm entries but mostly numerous mergers and acquisitions.

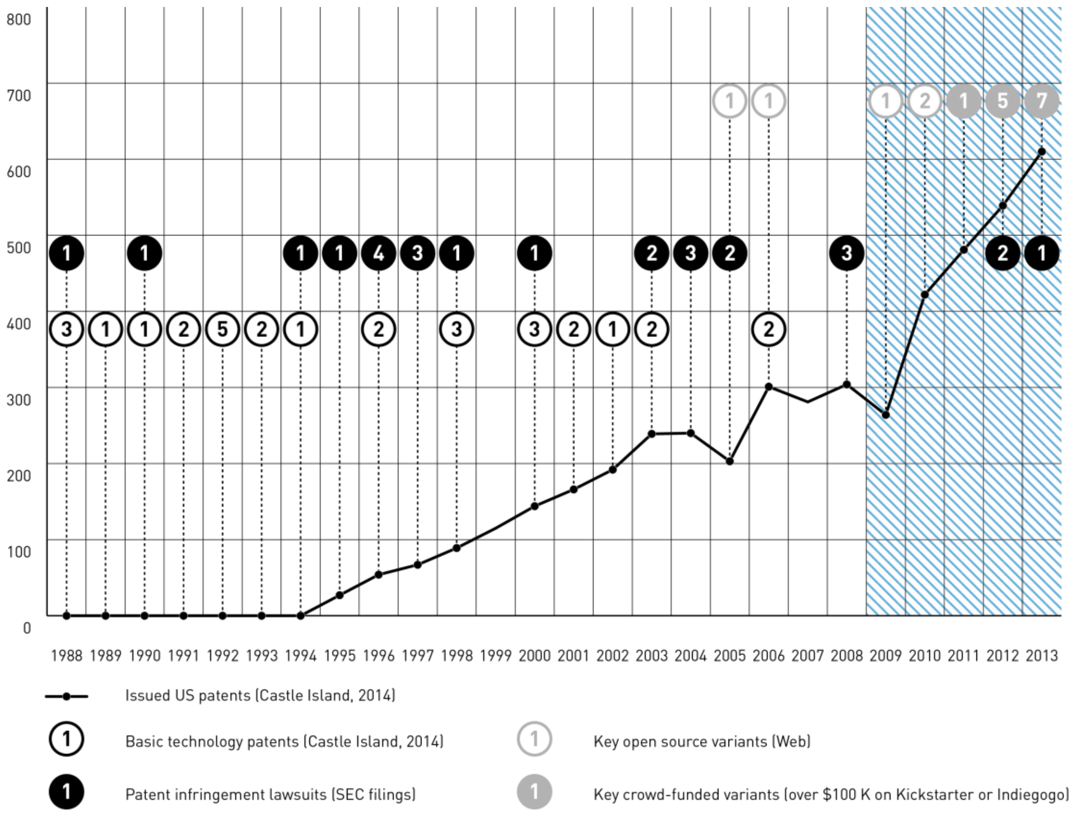

Figure 13: Key patents overlaid on issued US patents for Additive Manufacturing.
Source: Robinson and Lagnau (2015)

Figure 4 shows the growth in patent publications and the key basic technology patents in the field. Of interest here, above the evidence of increasing investment in protection of invention, is the existence of patent specific infringement lawsuits in the mid-90s onwards as well as, I the last period, the rise of open-source variants of AM machines. The latter is related to the ending of the restrictions on some key patents, and coincides with the spike in number of machine supplier firms (see figure 3).

There seems to be in both graphs two phases (we have highlighted phase 2 as 2009 and onwards, Robinson and Lagnau 2015). Initially additive manufacturing was based on printing with plastics, suitable material for prototypes and architectural designs, and by the mid-2000s, plastic-based additive manufacturing reached a state of technological and economic maturity (Campbell et al., 2012). This coincided with the growing availability of metal-based AM process technologies and the emergence of a new vision of utility, namely rapid manufacturing. Following a series of patent infringement lawsuits, acquisitions and failures (Figure 4), the RP industry has consolidated around a small number of specialized supplier firms and service providers catering to the well defined niche requirements of a specific set of professional users. Since most patents have expired or will expire in the next 5 years (Wohlers, 2013b), this status quo seems to be crumbling, particularly due to the recent proliferation of open-source variants of additive process technologies initially used for RP.

These performance descriptors and markets are helpful to observe the measurable growth of activity in a field in terms of industrial activity and market structure.

However, this hardly gives indications about the lasting embedding of a new technology in markets. For this we need complementary analyses of institutionalisation processes, which, like for research, we propose at two levels: anticipatory coordination (similar to programming for research) and 'market framing' through rules norms and values, which we propose to call 'market infrastructures'.

3.5.2. Anticipatory coordination out of niches: arenas for defining future worlds and the path towards them[51]

Moving out of the niche level to reach a wider market involves enrolling supports and building a collective. It requires presenting a coherent and convincing view of the world and of the institutions within it (Suchman, 1995, Robinson and Lagnau 2015). Actors often collectively organise themselves by creating roadmaps and strategic agendas. They set targets collectively so that they can align technologies to be ready and complementary at the same moment. This is specifically the case for radical innovations that require working on various aspects both technologically speaking for producers and for the market for users.

At the micro-level of individual firms, there is by now a wealth of literature on the function of roadmaps in private organisations (Groenveld 1997) and tools for roadmapping (Albright and Kappel 2003; Barker and Smith 1995; Kappel 2001; Kostoff and Schaller 2001; ATBEST 2005, McCarthy 2004; Phaal et al 2004;). For the purpose of our paper we highlight three important tasks that firm level roadmap projects have to accomplish (a) Exploring (prospecting) technology and application (market) futures, (b) integrating technology and business strategy; and (c) defining (and managing) project trajectories (single projects or a portfolio of projects).

However, for breakthrough technology fields, analysing individual firm's roadmaps may not lead to any great insights into the embedding of a technology into markets.[52] We argue that analysing collective roadmapping and agenda setting activities provide much more insights into what is occurring. The International Technology Roadmap for Semiconductors (ITRS) is an example of strong collective anticipatory coordination: all actors involved in the development, the design, the production and the use of electronic chips produce a roadmap in which technological targets are set and evaluated for a range of five so-called "technological generations". The chip manufacturing process is so complex and includes the work from so many actors that without the

[51] The case examples of anticipatory coordination in nanotechnologies was first presented in the MDET session at EU-SPRI (Robinson 2014) and are further elaborated in an article in preparation (Robinson forthcoming) focusing on arenas of anticipation in nanotechnology.

[52] Robinson and Propp (2008) point out that there was a proliferation of project level roadmaps for nanotechnologies in the NMP and IST activity areas in the early 2000s. and that they were not coordinated. For example for nanoelectronics, the original ENIAC's Vision 2020 document (June 2004), there is no reference to (IST-FET's) Technology Roadmap for Nano-Electronics from 1999 (1[st] edition) and 2000 (2[nd] edition).

roadmap they could not provide the technological components to reach the market in an efficient manner (Kahane et al. 2012, Robinson forthcoming).

For the case of nanotechnologies, observing arenas for roadmapping and agenda setting are interesting for exploring how the field is moving from a niche community (based on research and development) into a process of generalisation. Some of the earliest roadmapping activities occurred with MANCEF (The Micro and Nano Technology Commercialization Education Foundation), which grew out of the microtechnology community of the 1990s, with the mission to accelerate the commercialization of micro/nano technologies by connecting researchers, suppliers, funders and policy makers.[53] Walsh (2004) reports how in MANCEF's roadmapping exercise for 'top-down nanotechnology', certain requirements of traditional roadmapping approaches could not be met: such as the definition of the scope and boundaries of the technology; specification of technology drivers and their targets; and identification of the product that would be the focus of the roadmap. Walsh further suggests that, rather than considering the product-market paradigm, the technology product paradigm is the entrance point into roadmapping: a company uses a technology to form a 'core product', which is then used as a platform to derive application-specific products from. Observing the MANCEF roadmapping activity enables to observe how collectively visions of future worlds are developed and then linked to potential technology development activities that the collective could prioritise over other options.

More recently, we have observed a multiplication of roadmaps and corresponding arenas that are linked either to applications such as nanomedicine or nanofood, or to industries such as nanoelectronics. These roadmaps tell us about differentiation dynamics and the growth of application oriented deployment of the technology. It mirrors also a semantic movement, which sees more and more actors speak of nanotechnologies (the plural) rather then the singular nanotechnology. Studying these roadmaps helps delineating the types of articulations at stake (between segments of the industry and more and more between the industry and user industries or communities), and their elaborations of the 'frontiers' represent important resources for discussing public/academic research agendas. We take the example of nanoelectronics and the European roadmaps elaborated in the mid-2000s to illustrate this.[54]
ENIAC is the European Technology Platform for Nano-electronics, drawing up strategic plans with strong involvement of key industrial actors like Siemens and Philips[55]. The name ENIAC, European Nanoelectronics Initiative Advisory Council,

[53] MANCEF is the US based Micro and Nanotechnology Commercialization and Education Foundation; cf. http://www.mancef.org/

[54] This example is based on Robinson (2014) and an earlier conference paper Rip, Robinson and Te Kulve (2007).

[55] "Technology Platforms … bring together companies, research institutions, the financial world and the regulatory authorities at the European level to define a common research agenda which should

illustrates that it is not just a European Platform for Nanoelectronics semiconductor firms, but that it also tries to enrol further stakeholders and interested actors[56]

The diagram below shows the Nanoelectronics roadmap commonly referred to in ENIAC and other Nanoelectronics fora. It illustrates the view that coordination beyond semiconductor manufacturing is necessary (for example for systems-on-a-chip). The notion of heterogeneous integration, where systems-in-a-package (SiP) will be necessary to add value to Moore's Law, is another driver.[57]

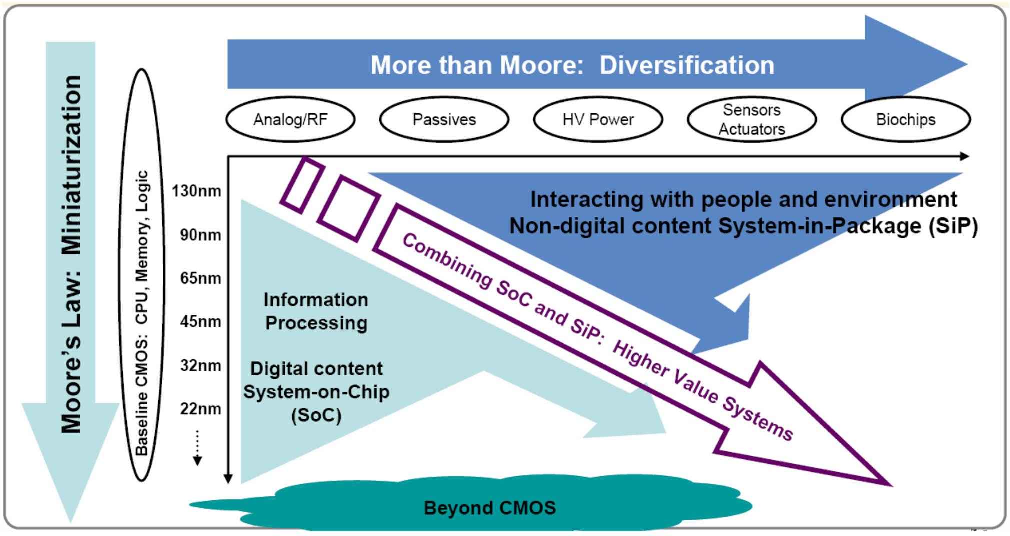

Figure 14: The Nanoelectronics Roadmap (www.eniac.eu)

Figure 14 highlights this push for coordination beyond systems-on-a-chip (SoC) to systems-in-a-package (SiP): they are placed in the Nanoelectronics context and endogenise, into the coordination activity, previously exogenous elements (see bubbles beneath the More than Moore arrow). This goes beyond the traditional coopetition of chip manufacturers and broadens to a wider community of actors and industries.

> *"For the More than Moore business, there is a clear need to standardise and commoditise some of the required technologies and designs in order to enable product manufacturing to be quickly ramped up to an economic scale. This can only be achieved by establishing structured cooperation within the electronics sector." (ENIAC Strategic Research Agenda 2006)*

mobilise a critical mass of - national and European - public and private resources." (EC COM(2004)353

[56] The email to stakeholders by Fred van Roosmalen is indicative of such opening: "You are invited to submit an Expression of Interest (…) submitted via email to Fred van Roosmalen..."). Fred van Roosmalen, director technology partnerships of NXP Semiconductors (formerly Philips Semiconductors), is another good example of the role of institutional entrepreneurs (in this case for constructing and driving ENIAC).

[57] We note that the major part of the roadmap addresses micro, rather than nano. In a sense, that is as it should be, because the eventual effects of nano depend on how it can be taken up at the micro (and meso) level.

Roadmaps do not only define technologies. Most of the times, they define a global view of the market and its relevant players, and of their relations. As outlined another MDET study related to roadmapping in the high speed train sector, arenas of anticipatory coordination can be endogenous, mobilising representatives of the train manufacturing industry, or exogenous, including broader players such as governmental agencies, regulators and user representatives (Moretto et al. 2015). In this case to-date there is indication of a transition towards endogenous/exogenous hybrid roadmapping activities. Zooming into such arenas can give insights into the degree of embedding of a technology field. The figure 15 below, plots the s-curve of high-speed train development, in terms of actual and projected (but loosely defined) developments on the y-axis, and time on the x-axis. We have overlaid the major strategic agenda reports and roadmaps from both key players (Alstom, Siemens etc.) and arenas for coordination (ERRAC). Like nanotechnology and semiconductors, high speed trains as they move to evermore complexity require more coordination, that is technological roadmapping (see the proliferation of reports from dedicated arenas and technology assessment agencies along the s-curve for 3rd generation technology), and also broader foresight activities looking at grander challenges that will shape the transport system (top-right hand corner concerning beyond the 3rd generation).

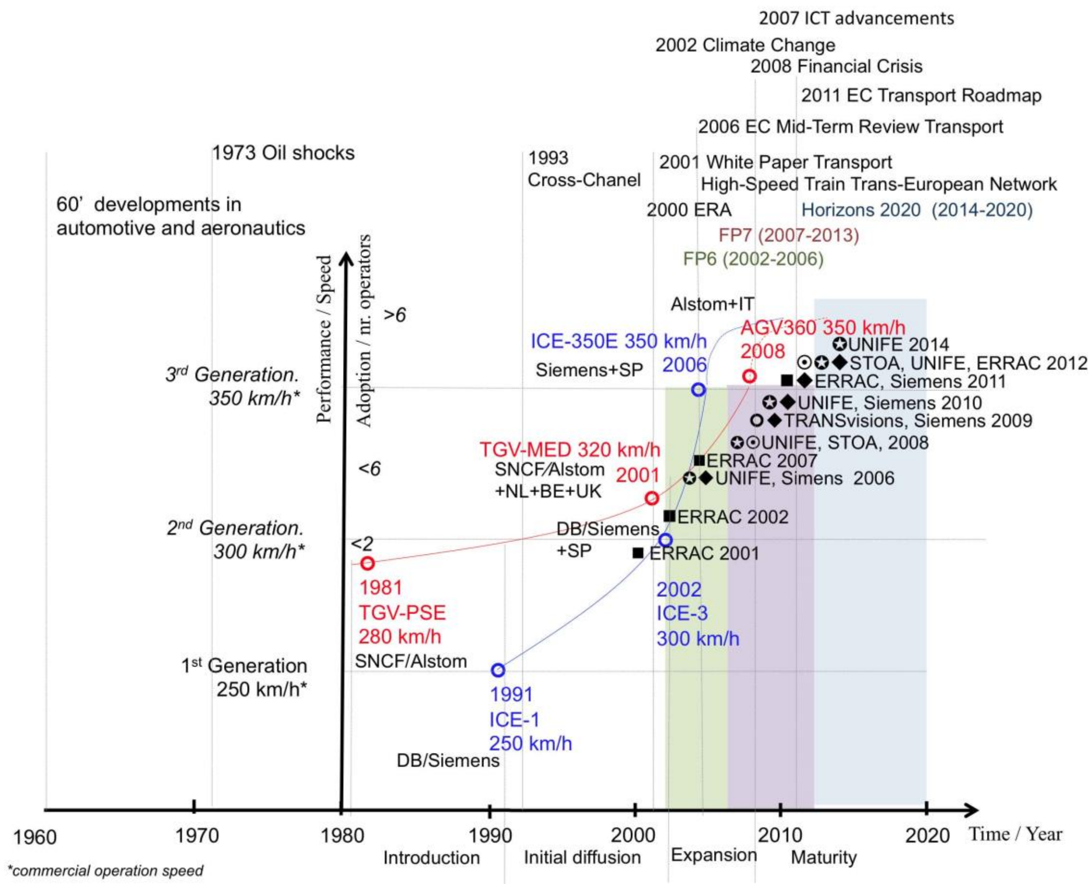

Figure 15. High-speed train technology innovation over time (s-curve)

Source: (Moretto, Robinson, Moniz and Chen 2015)

This last example shows another important dimension of technologies ‘in act’, the key role that existing professional associations and technical conferences play in anticipatory coordination. Moreover, they act as industry community builders. Following the ‘national’ and ‘international’ associations that are built around a new technology is thus central to identify the actors that are engaged in the field, the type of coordination and alignment mechanisms they have built and/or are building, and the type of anticipatory activities they develop. We have found similar aspects than those mentioned for research, the role of champions (Delemarle 2014 for the case of asynchronous chip design) in their deployment, differentiating the type of activities they deploy (see our 4 types above). The work on the governance of nanotechnology has added another important aspect that is the organisational aspects and the resources at their disposal for their activities to be lasting and performative (Delemarle and Laredo, 2014). One last aspect underlined by the additive manufacturing case, (Lagnau and Robinson, 2015) lies in the articulation between collective spaces discussing research and industry: in the latter case the two are joint so that the ‘professional’ associations cover both the academic and technical dimensions. This is a critical feature for agenda setting and for anticipating the continuity between public and private endeavours.

Coordinating out of niches requires more than shared visions and alignments, it also requires the infrastructures that enable markets to emerge and survive. These *market infrastructures* are the focus of the next section.

3.5.3. Market Infrastructures and the Framing of Markets

Market infrastructures are the basis for the structuring of future markets. For us, unfolding this concept is the key to analyze how intended radical innovations move out of their protected spaces, as described in the section above, and transition from the exploration phase of emergence to the exploitation phase (March 1991).

Fligstein (2001) has argued that market building results from a political process in which the State plays a particularly important role. He defines four necessary rules that are embedded in society and which underlie any exchange, which he labels “market infrastructures”: property rights, governance structures, rules of exchange, and concepts of control. However, these four rules are macro elements, and do not explain how specific innovations move from their original protected spaces and diffused more broadly. Delemarle and Laredo (2015) mobilize Callon’s approach of the “framing and overflowing” of markets (1998), which has three benefits: first it introduces a dynamic dimension into the discussion of markets. Second, it includes the notions of actors and of their strategies. Third, it brings in the notion of the “framing” of markets. The frame defines what is important and what should be the focus of actions, what and who should be in the frame and what and who should not. But this is also a dynamic concept: whenever new issues arise in markets – that is when ‘externalities’ generate issues that cannot be dealt within the existing frame – an ‘overflowing’ happens, which results in the emergence of a new arena that takes these externalities into consideration. Negotiations within the arena lead to a robust compromise (Rip, 1986) and the creation of a new frame that internalizes – at least partly – what was previously external. Callon argues that market frames are constantly overflowing and so changing: static frames cannot deal with all possible issues and need to be periodically updated. To conclude, markets need framing, and framings require infrastructures: *they are defined as a set of rules (what actors are allowed to do), of norms (what they ought to do) and of values (what they want to do).* While some are intangible (embodied in the way actors behave), most are embedded in physical equipment (like Goffman's theatre, communication networks or transport networks and their support systems, e.g. containers for shipping); in formalized processes that build on specialized certification and validation bodies; or/and in legal obligations (with corresponding legislative and enforcement structures). Such a definition assumes that there is not one infrastructure to frame one market, but a set of them that build an infrastructure set or what Abernathy de facto called "architecture". Once the infrastructures of a given market are stabilized, they become "naturalized" following Latour's terminology.

We have used the nanotechnology case for discussing the notion of market infrastructures (Delemarle and Laredo 2015), and show that in the nanotechnology case, there have been misalignments between Governments (which discussed one transversal nanotechnology market) and firms, which considered nanotechnology as a tool to enhance functionalities in existing markets. In other words the former worked towards building one market infrastructure based on the enabling technology itself whilst the latter considered the specific questions raised by the insertion of nanotechnology in multiple distinct existing markets.

This is illustrated by the work done on different value chains incorporating nanotechnology dimensions (Robinson, 2011). What becomes visible, is that the broader development of what constitutes a market infrastructure for a single "Nanotechnology" industry begins to come under tension when nanotechnology supply chains enter products incorporating nanotechnology dimensions (e.g. various nanomaterials entering the food packaging sector). They enter in different parts of various value chains and in quite diverse sectors with incumbent "naturalised" market infrastructures already in place (see figure below for an illustration). For nanomedicine (D'Silva et al 2012), even the most rough division of nanotechnology for health applications produces three very different regulatory and generalization routes calling for exploration of more targeted market infrastructures.

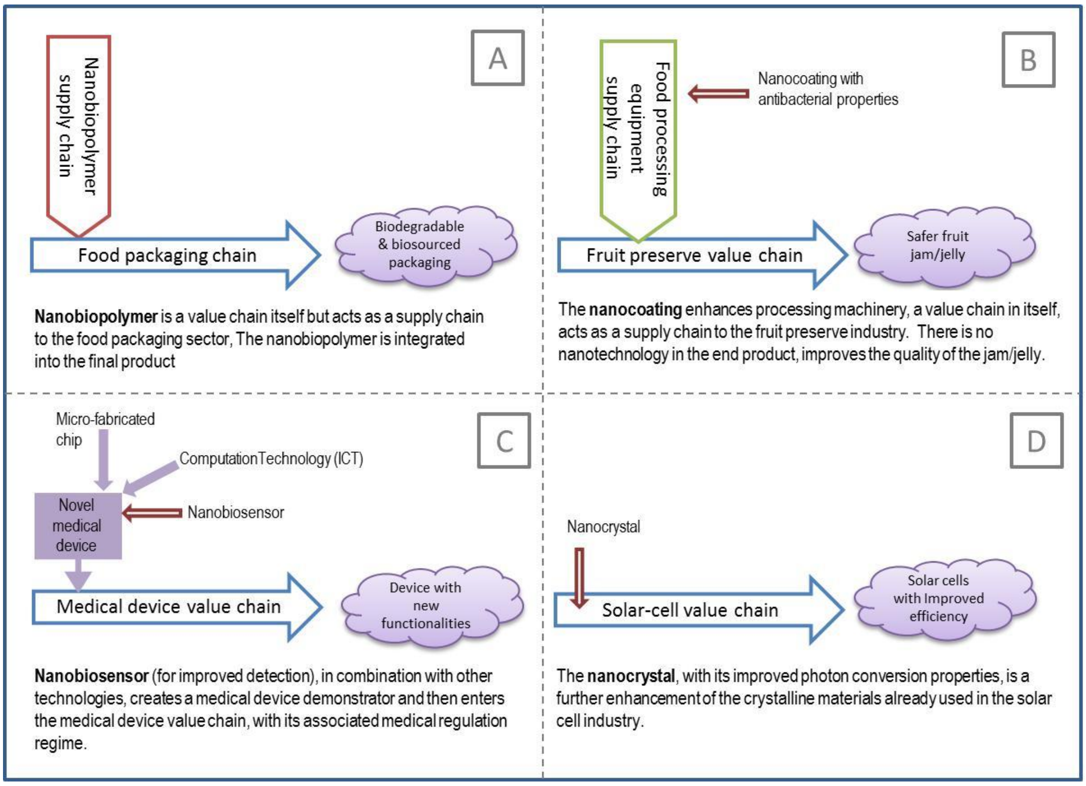

Figure 16. Four examples where nanotechnologies affect a value chains leading to products (the red arrows in the diagram indicate where nano enters the game)

Source: Robinson and Rip 2013.

This clearly highlights the fact that a one size fits all market infrastructure is not suitable for nanotechnology. The key point here is that, since nanotechnologies are enabling, they add value to new products and applications depending on what is happening in these domains. This question of the 'adequate framing of markets' has driven us to investigate in depth these aspects marginally addressed before (see Delemarle & Laredo 2014, 2015).

The question that we face is whether such a situation is specific to generic, transversal technologies, or whether we find it in more specific developments. Ismael Rafols has suggested that in most technologies we should have a similar approach and differentiate between shared core elements and application-oriented developments. Our case on additive manufacturing shows that this pattern of 'branching' also apply to very targeted technologies (Robinson and Lagnau, 2015) once they get out of their 'niche'. This means that we have to be careful in studying the relations between one 'technology' and the markets in which it is embedded. What we have also learnt is that market framing requires extensive work that actors conduct from within the protected spaces that have been created. As public action is often critical in the creation of these protected spaces (mostly through programme funding), what is striking is their quasi general absence from present funding programmes while these were important aspects of public funding in the 1970s (policymakers then spoke of 'prenormative' programmes) and in the 1980s, (think of the role EC programmes have played for the GSM norm or for the regulation of wind mills). This may well explain the deep misalignment between policy understanding of new technologies at the nanoscale and industry search for tailored and differentiated ‘market infrastructures’.

3.6. Discussion of research and market embedding

That embedding occurs was a “bet” made by the MDET project. We hypothesized that it was an important component of the emergence and unfolding of new technologies, but at the same time, theories as well as tools and methods were completely lacking compared to the socio-cognitive positioning (section 3.1) or even to the analysis of field level institutions (section 3.2).

After first explorations, the concurring work done by Barré and colleagues have helped us to structure an operational approach for research dimensions and have enabled us to focus on market dimensions. The disentangling of policy and systems around three functions (orientation, programming and performance) has opened a new avenues enabling, in particular, to ability to develop practical ways of following the emergence and deployment of public / collective programmes supporting the emerging technology. It has also helped to identify the importance of what happens at the local level of performing organisations and enabled us to develop an approach for assessing the embedding of the technology and its key actors in their employing organisations.

Similarly the work done on ‘transition theory’ has pushed us to reconsider the ways in which we analyse the research-society interactions, building on the notion of protected spaces, and asking for more focus on ‘how technologies get out of niches and penetrate society’. This has been a major focus of the work done, looking at how anticipations and promise champions combine in shaping alignments, and at what needs to be redesigned in markets for the new technology to prosper. We have proposed the notion of ‘market infrastructures’ as a central device translating the collective dimensions needed for markets to exist. The example of nanotechnology shows that it is powerful to characterise both situations and dynamics, and understand potential (mis)alignments.

The cases have shown a third important element: we should be cautious in assimilating first market deployments as the end of the emerging phase; first markets can also correspond to niches which do not enable any further development (as was the case of chips based on the asynchronous design). And the additive manufacturing case shows that first markets can be the source of ‘positive’ overflowings, that de facto pave the way first to far wider diffusion and second to new research alleys for future enlargements.

The two cases of nanotechnology and additive manufacturing illustrate how powerful the framework proposed can be. Using only few cases (we have studied more) it enables us to show how approaches to observing embedding in research and in markets can be undertaken only using publicly available data sources (whether paid for or available for free) all the time. It also shows that the tooling needed is not very complex. However the range of tools is quite large. The examples mobilised did not aim at a systematic coverage of this range of tools but rather showing how progression in the analysis can be organised in order to select both the most relevant tools and the pertinent level of deployment.

Conclusion

How did we cope with the issue raised in the introduction– how to “characterise “emerging technologies” in order to define relevant policies?

It is important to come back to the initial idea of the project. The project was based on the accumulated knowledge in recent scientometric and indicator work that help to analyse ‘socio-cognitive’ dynamics, in particular coping with the approach proposed by Bonaccorsi of search regimes. The hypothesis, based an initial work (then) by M. Nedeva was that we should not forget that dynamics concern simultaneously ‘fields’ and ‘spaces’. The former can be in great part captured by socio-cognitive approaches, while the latter deals with the institutional embedding of research activities. The former takes place above geographical borders (ideally at the world level) while the latter depends on how countries organise their research systems, and, within systems, on the choices that performing actors can make. We have used cases to learn about how to take these dimensions into account. This has driven us to mobilise the policy framework developed by Barré and colleagues in parallel to the MDET project. This has enabled to propose a framework and operational processes to understand the institutional embedding of research.

A second difficulty was that technology is neither research per se (on which most scientometrics focus) not innovation (based upon new products on the market). While the former has witnessed significant investments around ‘frontier science’ and the developments, in particular in Europe, with the ERC, the latter remain poorly studied. Recent theoretical developments have identified the critical role of ‘protected spaces’ or ‘niches’ as key processes that help the emerging technology to demonstrate its potential value. However there has been little work on how the new technology can get out of its protected space and enter markets. One of the difficulties lies in the fact that it is not technologies that enter markets, but the products that mobilise them and either propose new uses or deeply modify existing uses (by adding new functionalities most of the times).

This has been the focus of the 3 cases we have developed during the project. We have revisited a technology previously studied at an early stage, asynchronous chip design, which has not yet (at the time we write) succeeded in getting out of its initial market ‘niche’. After having studied the quantitative and policy dynamics of nanotechnology before the project, we have focused during the project on attempts to frame markets, and the analysis of the very different and often contradicting attempts have helped us understand that actors also use niches to try and shape future markets, but that there was no systematic approach that could help follow these attempts and their unfolding as they happen. We have devised a new approach of what we call ‘market infrastructures’. Our third case has been to consider a technology that has emerged without structured public investment, a rare case since the second world war. Today called ‘additive manufacturing, it emerged as ‘rapid prototyping’ and then 3D printing. The study of the triad that constitutes systems (machines, software and materials) has enabled to look at how systems find their way and understand modes of deployment where initial markets help the construction of a 'field' and are a source of 'path branching'. This type of dynamics poses new questions to public intervention, and first the ability to grasp such dynamics.

Combined with the work of our SPRU colleagues on science-driven technologies on one side and on 'hidden innovations' on the other, this has helped us to propose a framework and corresponding tools embedded in what we call our 'five petals' flower of technology emergence characterisation. The image below summarises it once again.

Figure 17 – Five approaches combined to map the dynamics of emerging technologies

Its first component lies in socio-cognitive dynamics, **delineating a technology field**, mobilising the now well-established set of scientometric approaches. However an initial problem, how to delineate the productions of the emerging field, has been very poorly addressed. It is though a critical issue since, by essence, an emerging technology / field, corresponds to no pre-existing classification, and has thus to be framed ex-nihilo. Most methods tend to use expert say in providing an extensive vocabulary that enables to download articles. We had already opposed this view looking for fully lexical approaches, and had proposed a first approach (published in Research Policy in 2007). We have considered within the frame of this project that it was important to extend it so that it better captures dynamics of search (and in particular the failed attempts). This new approach has been fully tested and implemented on a first very large dataset (nano science and nano technology). We consider it as the first major quantitative result of this project. Most of the questions we ask when analysing the datasets are linked with key authors, key organisations and key places. While we still rely on the first two on 'computer aided manual work', we have made extensive efforts to devise world-level geolocalisation and clustering methods. They have remained at the pilot stage, and are now being fully operationalized within the new European research infrastructure on data for research and innovation studies (RISIS). RISIS also aims at generalising ‘registers’ and ‘reference databases’ on organisations, with an impact for analysts in one place to tap what happens elsewhere with a good degree of reliability. Using solar energy, we show what a ‘standard’ report could look like.

Its second component lies in **field level institutional conditions**. In the first chapter we have summarised the six key attributes of a field: the cognitive set of problems that are shared and build its research agenda, the technical norms that insure quality, the cognitive, technical and institutional complementarities with other fields, the journals and conferences that foster knowledge circulation and exchanges, its dual dynamics of extension, and capacity building. To say it otherwise, a technology to emerge requires a collective space and a community of researchers (whether public or private) that: (i) build a common understanding of what the technology is, (ii) defines its key attributes that nurture capability building, (iii) organise the circulation and exchange of knowledge, (iv) discusses the ways to push the technology in the outside world (in particular through visions and demonstrators), and (v) identifies the problems still pending that build its research agenda. This provides references against which analyse the situation of a ‘want to be’ new technology. We have used additive manufacturing to look at how these dimensions can be followed, and we have used our own field to show how important are the simultaneous presence of these dimensions and their articulation.

Its third petal deals with the **role of ‘promise champions’ and of expectations**. The central argument can be summarised as follows: an emergent technology needs key actors that push it in the wider world, and thus are the ‘spoke persons’ of the want to be technology. The classical management literature assimilates these to ‘institutional entrepreneurs’. Looking at our cases, we think that this is not the only type, and often for an institutional entrepreneur to emerge, there needs to have been other types of entrepreneurs: we have identified three: cognitive references (the ‘fore fathers’ of the field), expectation pushers and promissory organisations. The latter appear to play a growing role over time: a classical situation was that this role was taken by the organisation that supports the community itself and organises its journals and conferences; but our recent cases have seen the emergence of specialist consultancies that dedicate themselves to gathering and structuring data that render visible the investments made, and play a specific role in anticipating future markets (and building quantitative anticipations, as we have shown both for nanotechnology and additive manufacturing). Institutional entrepreneurs (our last category of champions) are nested in their spaces, and thus as for governance, entrepreneurship is distributed and the successes of some fuel the success of others (as we can see in nanotechnology, from the success of M. Roco in the US to this of J. Therme in Grenoble). Identifying these entrepreneurs, mapping the spaces in which they are active, following the visions they produce and the organisational solutions they propose is thus a central aspect to measure the degree of ‘embedding of a technology.

The fourth and fifth petals are then focused on analysing the **degree of 'institutional embedding'** of the technology. The choice of the wording is important: Sociologists of science speak of the 'naturalisation' of a phenomenon that is when it is no longer discussed and taken for granted in all other debates. We use 'embedding' to analyse this process. We start by the embedding of research activities, before elaborating about the embedding in markets.

As said above the proposal by Barre of disentangling systems at the three levels of orientation, programming and performance has helped us tremendously in evolving in our operationalization. We have shown how we 'have translated into analytical lenses to look at what happens in given spaces (not only others but also the space where the analyst is located). Our work has focused on the two levels of programming and of performance.

At the programming level, we propose four major entry points for looking at forms and degrees of institutionalisation. The first one deals with the respective roles of project-based funding agencies and of PROs: are the latter taken as any other performing entity, or are they given a specific role parallel to this of funding agencies (for instance in term of facility building)? The second one deals with the existence of dedicated funding programmes, their location, their absolute and relative importance, their research agendas and their activities. The third one is to consider the existence of CSOs that play a role in shaping agendas and legitimising the WBT field, provide resources and sometimes engage in performing activities. And the last one deals with the processes put in action to organise action and channel funds, in the wake of recent work done of 'policy mixes' and the portfolio of instruments, energy agencies (and in particular ADEME) being good illustrations of how to build 'visions' and 'roadmaps' of a problem and to connect to it the spread of instruments and their sequence of deployment. It illustrates the fact most programmes and agencies dealing with research forget, that 'one size does not fit all' and that there is an urgent need to diversify the portfolio of instruments.

Our second effort, and probably the most important development proposed, is to focus on the local embedding of research. Individuals are not enough to enable a technology to emerge, there needs to be organisations that share this 'stake' and translate it into organisational features that make efforts sustainable and lasting: research collectives for knowledge production and accumulation, curricula for capability building, structures to foster knowledge circulation. We have developed a process to monitor how key actors for the field are embedded in their employing organisations, and how their organisations support them and the want to be technology. The case of additive manufacturing shows how important this is especially when the programming level is weak or nearly absent, and this mirrors the European vision 2020 about the need for 'strong organisations' in research.

Embedding of the technology in markets has corresponding levels to orientation, programming and performance, but they take very different forms. A first lesson from our cases is that initial embedding in markets does not always translate an 'end of process' situation; it often is linked with the creation not of 'research or technology niches' (the case most studied) but of 'market niches', an issue well known in management studies. Characterising these niches, and what type of industrial actor dynamics they correspond to, becomes then a central issue of performance to understand what issues are faced for the diffusion / generalisation of the technology. This is central to consider when technologies start entering markets as is well illustrated by the example of additive manufacturing. The programming dimension corresponds to collective anticipations of markets: the example of the nanotechnology roadmap shows how the semiconductor industry organises itself in Europe, and how this enables to anticipate the transformation of the market with the arrival of nanotechnology solutions. In this case, the roadmap produced envisages completely different articulations with user industries moving to 'systems on a chip' to 'systems in a package'. The orientation dimension in markets is of another nature, it corresponds to the 'framing' or 'shaping' of markets (the former pushed by sociology and the latter by management studies). It stands on the fact that markets are not 'out there': that are so only when they are stabilised, 'mature' and are thus 'out there' when we consider incremental / cumulative innovations (as they represent 90% of total firm activities and investments, this is what management studies focus upon). Thus we have to focus on the work being done by actors to 'frame' markets in a way that the technology can circulate and diffuse out of the niche. One important result of the project has been to show, using nanotechnology, that actors invest heavily in such activities, that they do so thanks to the established niches, and that they follow their preferred 'ways of doing', e.g. government actors prefer regulatory activities, while firms tend to invest more into norms and standards. We have proposed the notion of 'market infrastructure' to bind together what actors try to stabilise, that is the *set of rules (what actors are allowed to do), of norms (what they ought to do) and of values (what they want to do)*. There are two implications into this definition: the first is to analyze the specific dimensions that need to change for the technology to diffuse (it is seldom all aspects and most of the times focused on one); the second one is to identify the arenas in which actors invest, and the activities they develop. The exemplary case of nanotechnology (which is still on-going) shows how many 'arenas' have been invested in, it shows also that many have already failed and that the notion of one market has vanished, leaving room to a new balance between generic principles to satisfy and specific development associated to the different application areas. One question this analysis raised lies in the role public policies can play in 'market framing/shaping', an old issue becoming relevant again (see the importance of 'pre-normative research programmes in the 1960s and 1970s).

The approach developed by MDET as a project has been 'performative': cases have helped us to propose a framework and to think of an application process and of the tools/methodologies needed to implement it in the frame of public funding agencies.

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Appendix 1 – Project outputs

Journal articles published or submitted

- Delemarle, A. and Larédo, P. (*forthcoming*) Tentative governance for new markets by creating market infrastructures. Submitted to a special issue of *Research Policy*.
- Delemarle, A. (2014). A rationale for public intervention in disruptive technological development: public policy tools as trust-enabling mechanisms. *Technology Analysis & Strategic Management*, *26*(1), 23-35.
- Robinson, D. K. R. and Lagnau A. (*in review 2015*) Innovation Pathways in Additive Manufacturing: Comparing budding and branching paths from rapid prototyping to alternative applications in science and markets. Submitted to *Technological Forecasting and Social Change*
- Moretto S., Robinson, D.K.R. and Moniz, A. (*submitted for review*) The role of endogenous and exogenous FTA in the European high-speed railway innovation system. Submitted to the special issue of *Technology Forecasting and Social Change* entitled "STI Strategy Making via Technology Road-Mapping: Implications for Theory, Policy and Practice"
- Postada, A., Parandian, A., Robinson, D.K.R. and Zybura, J. (*forthcoming*) An alignment approach for an industry in the making: Diginova and the case of Digital Fabrication. *Technological Forecasting and Social Change.*
- Robinson D. K. R. and Boon W. P. C. (*in preparation*) Business models and their industry scenarios. A demonstration for 3D bioprinting. In preparation for the special issue of *Technology Forecasting and Social Change* entitled " Social Change through Healthcare Quality Innovation"
- Robinson D. K. R., Boon W. P. C. Lagnau (*in preparation*) Does 3D bioprinting mean business. In preparation for the journal Biofabrication
- Robinson, D. K. R. (2011). Value chains as a linking-pin framework for exploring governance and innovation in nano-involved sectors: illustrated for nanotechnologies and the food packaging sector. European Journal of Law and Technology, 2(3).

Book Chapters

- Robinson, D. K. R., Rip, A. and Delemarle, A. (forthcoming) Nanodistricts: between global nanotechnology promises and local cluster dynamics. Chapter 7 in Merz M., Sormani P., Biniok P. eds. The Local Configuration of New Research Fields. On Regional and National Diversity. Sociology of the Sciences Yearbook series. Dordrecht: Springer.

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- Delemarle, A., & Larédo, P. (2014). Governing radical change through the emergence of a governance arrangement. *The Governance of Socio-Technical Systems: Explaining Change*, 159
- Moretto S., Robinson D. K. R., Moniz, A. B. and Chen, S. (2014) Mind The Gap In High-Speed Trains Futures: A Methodological Contribution. Proceedings of the Second International Conference on Railway Technology: Research, Development and Maintenance, J. Pombo, (Editor), Civil-Comp Press, Stirlingshire, Scotland.
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Conference presentations

- Lagnau A. & Robinson D.K.R. (2015) Mobilising framing and overflowing to understand changes in evolving technology fields. Presented in sub-theme 25: Devising Markets and Other Valuation Sites. 31st EGOS Colloquium. ALBA Graduate Business School at The American College of Greece. July 2–4, 2015, Athens, Greece
- Robinson, D. K. R. (2014) Anticipatory coordination around nanotechnology innovation systems and industries: successes, failures and muddling through. EU-SPRI conference: Science and Innovation Policy, Dynamics, Challenges, Responsibility and Practice. 18-20 June 2014, Manchester, United Kingdom.
- Delemarle A. and Larédo P. (2014) What are the loci for the creation or evolution market infrastructures? Are they new and specific structures? A focus on organisational issues of market infrastructures creation or evolution. EU-SPRI conference: Science and Innovation Policy, Dynamics, Challenges, Responsibility and Practice. 18-20 June 2014, Manchester, United Kingdom.
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- Lagnau, A., « From Exploration to Exploitation : Additive Manufacturing in Transition », Assises Européennes de la Fabrication Additive, Paris, 24-26 June 2014
- Lagnau, A., « Fabrication Additive : État de l'Art / Cartographie des Acteurs / Enjeux », Sénat, Paris, 28 January 2014.
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- Delemarle, A., Lagnau, A., Larédo, P., & Douglas, R. (2013). Dynamics of epistemic communities and emerging technologies: the need for local embeddedness and spaces of exchange. In The management of innovation policies: new forms of collaboration in policy design, implementation and evaluation. Proceedings of the 2013 EU-SPRI Forum Conference. Madrid 10-12 April 2013 ISBN 978-84-695-7408-9
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- Delemarle A. and Larédo P. (2012) How do radical innovations generalise: the role of market infrastructures, ISI-EU-SPRI conference, Karlsruhe, June 11-13

Workshops organized

- Robinson, D. K. R., Delemarle, A. and Kahane, B. (2012) Designs on the Future in Asynchronous Circuits and Systems. Two-hour roundtable at the ASYNC 2012. 18th IEEE International Symposium on Asynchronous Circuits and Systems. May 7-9, Lyngby, Denmark. http://www2.imm.dtu.dk/async_2012/async/roundtable1.html

Symposia organized

- Robinson, D. K. R., Delemarle A. and Larédo P. (2014) EMERGING INNOVATION AND MARKET INFRASTRUCTURES. Special MDET session at the EU-SPRI conference: Science and Innovation Policy, Dynamics, Challenges, Responsibility and Practice. 18-20 June