The 'interpretive flexibility' of nanotechnologies in context: the case of a leading R&D center in Flanders, Belgium

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"Imagine a single area of scientific discovery with the potential to enable a wealth of innovative new technologies across a vast array of fields including healthcare, information technology, energy production and utilization, homeland security and national defence, biotechnology, food and agriculture, aerospace, manufacturing, and environmental improvement. Nanoscience (…) has this potential.

Advances in nanoscience and nanoengineering are already ushering in new applications—or nanotechnologies—that are leading to improved products across a broad realm of sectors, from textiles to electronics. Some of these improved products are already available, including improved catalysts, stain resistant fabrics, better sunscreens, superior dental bonding materials, high resolution printer inks, digital camera displays, and high capacity computer hard disks, to name a few".

(NNI, 2003, p. 1)

Introduction

"What a cute teddy bear, I am going to purchase it and proudly bring it back to my beloved daughter". There goes a father, walking around with its brand new gift, a sweet and cuddly Teddy bear wrapped in a nice and colorful package. Our man had accomplished his birthday task with careful attention and even some caution. The seller introduced him to Benny – the name of the bear. He advertised this toy as the softest and healthiest in the world. There was some evidence to it: Benny was honored with the "Family Choice Award" by Family Magazine, widely celebrated as one of the most "Family-Friendly" consumer awards. Pure Plushy is the firm that proudly fathered Benny the Bear and even

patented it. Wait? Since when would patent a teddy bear?

The sweet toy itself was not really patented, to the opposite of its wonderful feature of being the cleanest, even antimicrobial puppet on the market. According to its website, Pure Plushy would describe itself as a "*the first company of its kind, that through the use of a patented technology, is offering anti-mite anti-mold and anti-microbial plush toys. The technology involves infusing silver, a natural anti-mite, anti-mold and anti-microbe agent, nanoparticles—25 nanometers thick, about one 200 thousandth of a human hair—inside memory foam*". This is the politically correct version. According to Andrew Maynard[1], a long-timer in nanotechnologies' issues, a previous version of the website would make a rather different claim: "*Scientific Research has proven that Silver is a natural Anti-Mite, Anti-Mold and Anti-Microbe agent. Recent advances in Nanotechnology have demonstrated exciting new ways in which to put tiny microscopic particles of silver inside substances such as Memory Foam*".

So what? Asks our beloving father on purpose. So what? What if silver nanoparticles would penetrate in his daughter's body, either when she breathes or when she puts her bear in her mouth? What if these nanoparticles could even reach her body right through her skin, because of their infinitely small scale? What if the antibacterial effects of these silver nanoparticles would lead to weak down her natural defenses? What if the particles would somehow find

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[1]   http://community.safenano.org/blogs/andrew_maynard/archive/2007/12/15/benny-the-bear-and-the-case-of-the-disappearing-nanoparticles.aspx (accessed 2010-09-15).

themselves released in the environment, for example through the use of washing machine? What if... what if?

So many things our cautious father did not think of. Of course, one cannot know everything and the seller did not mention to him all these things about "silver antibacterial nanoparticles", neither was it written down on the package that he read carefully. This is precisely the point. Nowadays, nano-enabled consumer products are being released worldwide on the market and few people actually know about it. More generally, a whole lot of developments go on when it comes to nanotechnologies. Those hold great expectations but great fears as well, rely on powerful actors such as governments and industries, but sometimes encounter strong citizen opposition.

In this thesis, I aim at walking toward this complex reality and provide a sense of what is going on behind this strange though appealing name, "nanotechnologies". I want to unfold a small piece of the realities that lie behind. Throughout the following chapters, I will argue that a main feature of nanotechnologies' development is its actual diversity and heterogeneity. Therefore, it is extremely challenging to share a general account, which stands for each and every single kind of nanotechnologies. Rather, I will provide a very local, contextualized account issued from a field inquiry conducted in a large R&D center in Flanders, Belgium, from February to June 2010.

Basically, this thesis will be divided in two broad chapters. In the first chapter, I will start by elaborating a theoretical framework, unpacking my epistemological perspective on nanotechnologies. A strong, but nuanced, constructivist approach

fits best nanotechnologies' dynamics of development, characterized by its deep heterogeneity. I shall then document this statement of heterogeneity by documenting some the complex and sometimes paradoxical, let alone antagonistic developments of nanotechnologies, regarding either the expectations they raise, the public support they benefit from, the controversies they generate, the increasing blurring of the boundary between "fundamental" and "applied" knowledge they perform, or again their contrasted rather linear story. Once I detailed all these elements, relying on academic literature review and public policies analysis, I try to bridge them with the constructivist approach established beforehand. To do so, I explain why manifold challenges still justify further constructivist uptake on nanotechnologies, especially as for documenting, through empirical evidence, evolving practices of science and artifacts production. I conclude that in such a context of irreducible heterogeneity, the kind of case study I intend to provide is of renewed interest. To me, this first part is a necessary preliminary step while it must not be sufficient, as it needs to be complemented with a more grounded approach to one particular nanotechnological development.

In the second chapter, I then provide an extended case study, which relies on an important fieldwork realized in a large-scale Flemish R&D center called "imec". According to the first chapter, this study wishes to document the potential variations of an artifact in the making. In other words, the point is to engage with an institution that develops prototypes using nanotechnologies, and more especially with individual researchers. From this "micro" perspective, I aim at unpacking the manifold decisions made by individual researchers in their daily

routines, which turn out to lead to different sort of material consequences. This way, I wish to show the "interpretive flexibility" [2] that do exist, as I shall demonstrate, in the very design stages of a prototype, showing how the micro-decisions of some researchers could impact the overall outcome of the R&D process. I should proceed in three steps. First, I will introduce and situate my fieldwork as well as providing considerations relevant to my methods of data generation, collection and handling. Second, I pick up four different stories at an individual, "micro" level, unraveling dilemmas, practices, research cultures, strategies or mobilized epistemologies, in order to assess the relevance of the concept of "interpretive flexibility" as adapted to this inquiry. I initially thought that such an approach should make it. Still, I happened to find out very powerful structuring dynamics at play that would strongly constrain the actual research provided by the specific team I engaged with. So, in a third part, I will have my word about these institutional dynamics that play out in an increasing global competition context and that one absolutely needs to take into account if one is to restitute an image of what he witnessed as faithful as possible.

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[2] I further detail and explain my understanding of this concept of "interpretive flexibility" and more specifically the way I intend to use it, in the first chapter.

Chapter 1: A constructivist approach to nanotechnologies

1. The social construction of technology and its "interpretive flexibility"

In this section, I introduce the theoretical frame of the "social construction of technology", also known as SCOT (Bɪᴊᴋᴇʀ, Hᴜɢʜᴇs & Pɪɴᴄʜ eds., 1987). This program initiated *Science and Technology Studies* (STS) as a field of research. Although it came through multiple critiques, reformulations, interpretations and subsequent evolutions[3], it certainly remains relevant as a general approach to technological developments. It then needs to be refined and the extent to which (some of) these concerns are addressed has to be made explicit. I start by shortly presenting the epistemological roots of the SCOT theory. I then introduce its main components. In a third part, I focus on one of its key concepts, namely "interpretive flexibility". At this point, I explain why and how I intend to use this concept further throughout my case study. Then, I refine the way in which I will mobilize the SCOT approach, making clear that although it wasn't my primarily intend, my empirical data made clear that more attention to structures need to be paid within the framework of the SCOT theory.

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[3] For an early mapping of the work provided under the label "SCOT", see Pinch (1996).

1.1.   *Epistemological grounds*

The whole elaboration of STS and especially the SCOT theory undoubtedly grounds its epistemological approach in the "The Social Construction of Reality" (BERGER & LUCKMANN, 1966). This development belongs to the broader sociology of knowledge and advocates the idea that a particular concept or practice is always constructed, and further institutionalized, by a social group, through (extended) interactions. This activity contributes and shapes reality, which is therefore "socially constructed" in this respect.

Some epistemologists developed this theory of knowledge and specifically adapted it to scientific knowledge. This school of thought is best known as the "Edinburgh School" and was leaded by David Bloor and fellows, who developed the "Strong programme[4]" of the sociology of scientific knowledge (SSK) (for an introduction to this program, see BARNES, BLOOR & HENRY, 1996). To put it blankly, the main lesson to be learned from this epistemological perspective is that pure objectivity about nature is something to be forgotten. Rather, when something goes wrong with science, it is not because of human mistakes or commitments[5], but rather because of science itself. This statement is a rather crude interpretation of one of the core principles of this strong program that is the principle of symmetry. According to it, one must treat all claims equally, with same explanatory principle, independently of whether these claims have been judged "right" or "wrong" according to scientific criteria.

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[4] The current thesis is written in American English. Though, original expressions put into brackets are faithful to the original ones as their authors formulated them.
[5] This position neatly contrasts the rather normative perspectives on science as analyzed by Merton and fellows.

I won't detail further this strong program but rather address the "Empirical Programme Of Relativism" (EPOR), which originates from Bath school of though and which pushes forward this central principle of symmetry (COLLINS, 1981). The key issues that EPOR focuses on are disagreements, controversies, struggles or conflicts that spontaneously arise among the scientific community. The main goal to this program was to establish what is now a crucial tenet of STS work: "it could have been otherwise". It shows the intrinsic contingency of scientific knowledge (HACKING, 1999, pp. 95-99). Hence, EPOR would trace back the "interpretive flexibility of scientific findings" and document how, in practice, science is shaped through social interactions and how knowledge is constructed through some sort of almost judiciary "trials", as in the case of "gravitational waves" analyzed by Collins[6]. As it focuses on particular scientific controversies, EPOR privileges local situation, particular sites of controversies from which it is possible to unpack the controversy and its various components across a whole range of social actors. From EPOR, I intend to mobilize this particularly situated and localized approach, as it fits further developments in STS, especially the calls for "integrating" social and technical knowledge[7].

1.2. The Social Construction of Technology: a Theory

These epistemological grounds I call the "deconstructivist" stage, which was arguably a mandatory step for further "constructivist" approaches. The "Social Construction of Technology" (SCOT) is about the social construction of technological artifacts (BIJKER, HUGHES & PINCH eds., 1987). It sheds a theoretical

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[6] COLLINS, 1981.
[7] See below, pp. 33-38.

light upon the development of technological artifacts. As Pinch & Bijker put it, "*In SCOT the developmental process of a technological artifact is described as an alternation of variation and selection. This results in a '*multidirectional' model" (PINCH & BIJKER, 1987, p. 112 – emphasis added). What does that mean? First of all, the authors try to avoid linear accounts about technological innovation, like for instance the better new technology that overrules the former outdated one. Doing so, they claim justice for the left-asides, forgotten artifacts of the technological development. Secondly, they put a particular emphasis on the multiplicity of directions a particular technological development could have followed.

To make their point, Pinch and Bijker then take on an empirical case study that is the development of the bicycle. They consider a range of possible variations. They highlight the fact that, nowadays, the developments that occurred back then seem fairly obvious and straightforward but were actually, by that time, much more contested. As they put it, "*those variants were at the same time quite different from each other and equally were serious rivals. It is only by retrospective distortion that a quasi-linear development emerges*" (PINCH & BIJKER, 1987, p. 114).

Obviously, the SCOT program is rather similar with the EPOR, and attempts to bridge together the sociology of knowledge as well as the sociology of technology – as the title itself points out. It also draws on the possible variations of the technological development – its intrinsic "interpretive flexibility" – and on further "closure" mechanisms. Through those, an artifact gets over another one, a competitor so to say, and makes its way into society, alongside the same path that follows a scientific theory to get accepted and recognized throughout the

"scientific community" in general. Thus, it generates a broadly accepted consensus, which by definition excludes alternatives. This way, scientific "objectivity" as well as the material world we live in are socially constructed. Pinch & Bijker demonstrate "*that technological artifacts are culturally constructed and interpreted; in other words, the interpretative flexibility of a technological artifact must be shown* (…) *By this* [they] *mean not only that there is flexibility in how people think of or interpret artifacts but also that there is flexibility in how artifacts are designed*" (PINCH & BIJKER, 1987, p. 122). This approach I want to undertake in my case study – with special attention to the design of technological artifacts.

That said, the scope of the SCOT slightly differs from the EPOR one. I shall mention two of these differences. Despite the fact that SCOT and especially the notion of "interpretive flexibility" will frame my fieldwork, I intend to clarify these positions further. It can be said that SCOT focuses on social groups as key explanatory factors. Those are shaping technological choices. Pinch & Bijker (1897, p. 125) endorse this viewpoint, although Bijker made steps toward more structural perspectives later on (KLEIN & KLEINMAN, 2002). I want to insist on this element, as I do not intend to focus on social groups as such but rather on individuals operating within a research team and a given institutional context[8].

As in the case of scientific controversies whereas competing theories are involved in a "trial", in SCOT, competing artifacts are selected through a very social process. That is when "closure" or "stabilization" is reached or achieved (PINCH & BIJKER, 1987, p. 128). This implies, as in the case of bicycles, the

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[8] See below, p.

existence of well-defined, bounded, identifiable artifacts. I shall explain while introducing my fieldwork that such a requirement was not met in my case study – as a consequence, I needed to focus less on artifacts themselves but rather on practices, from the viewpoint of individual researchers.

Up to now, I traced back the epistemological grounds of the SCOT approach, from the strong program to the empirical program of relativism. From these, I addressed the way in which the SCOT approach elaborates on the same concepts of "interpretive flexibility" and "closure", even though it deals with technological artifacts rather than scientific knowledge as such. That said, I follow Pinch and Bijker's line in the sense that I intend to merge "sociology of knowledge" and "sociology of technology" in my case study. Actually, nanotechnologies fit the case for two reasons. As I shall argue, they are a *de facto* merging of both knowledge and technology, what Bensaude-Vincent called a "profile of technoscience" (BENSAUDE-VINCENT, 2009b). Second, nanotechnologies is still fairly recent. For instance, the seminal *National Nanotechnology Initiative* from the US was adopted no later than 2001. For this reason, it makes sense to raise the issue of interpretive flexibility before nanotechnologies reach closure and impacts markets to an unprecedented extent.

1.3. Structural considerations to the SCOT approach and subsequent interpretations of "flexibility"

While largely dominant as a paradigm in the field of STS, the SCOT approach did not go uncriticized. The stronger trend of criticism came mainly from French theorists who developed the program of the Actor-Network Theory (ANT).

Among them was Bruno Latour (LATOUR, 2005) or Michel Callon (CALLON, 1986). They basically stated that studying the social was not enough and that symmetry among all "*actants*", that is among all acting entities, either human or non-human. It was a kind reminder of this basic truth that technical artifacts *also* shape societies just as much as the other way around. They studied how certain objects would embody norms of behaviors, moral values or set of other imperatives that would constrain further human action (LATOUR, 1993). The main benefit of this approach is to balance the socially centered perspectives of the SCOT and bring the technology back in. It would eventually lead to the global recognition of a process of co-construction of technology and society, at least to some extent. This ANT approach I do not intend to follow, since the aim of my case study is to understand how a particular research team in nanotechnologies shapes the artifacts its member are working on, from within a R&D center. Especially, I believe the notion of "interpretive flexibility" is relevant to social playgrounds rather than mere artifacts, for which the framework developed by the sociology of translation definitely provides a better fit (CALLON, 1986).

Still, even if one limits the inquiry to the "social" perspectives rather than the material ones, critiques were formulated about this too. I shall elaborate only on one of these, which is of special relevance to the fieldwork. As I mentioned earlier, the initial aim of this study was to document the potential variations of an artifact, in the making. In other words, the point was to engage with an institution that develops prototypes with nanotechnologies and then to unpack the manifold decisions made by individual researchers in their practices and daily routines, which might lead to any sort of material consequences. This way, I

could have shown up some interpretive flexibility in the very design stage of a prototype, showing how the micro-decisions of some researchers could impact the overall outcomes of the R&D process. However, my findings proved this rather simplistic or naïve vision of technological development to be challenged by the empirical data I collected. For this reason, I also pay attention to structural considerations on the SCOT approach (KLEIN & KLEINMAN, 2002).

Kleinman defines "*structures as specific formal and informal, explicit and implicit "rules of play," which establish distinctive resource distributions, capacities, and incapacities and define specific constraints and opportunities for actors depending on their structural location. Power and its operation are then understood within this structural context. The rules of play that define structures give certain actors advantages over others by endowing them with valued resources or indeed by serving as resources themselves.* (KLEINMAN 1998, p. 289)". This notion of "structures" is fairly similar to the concept of "institutions", borrowed to the "new institutional economics" literature. "*Institutions may be defined as the set of conventions and rules of action that prevail in the economy, are embedded in the local social structure, and show a marked regional differentiation*" (KRÄTKE 1999, p. 683, cited in PARTO, 2005a). Institutions are indeed a manifold concept that allows for various levels of interpretations and embeds multiple dimensions, i.e. behavioral, cognitive, associative, regulative and constitutive (PARTO, 2005b). I do not intend to use such a complex and loosely bounded concept, as it would imply too much of clarifications.

Although these notions of "structure" and "institutions" are deeply intertwined, or even two different terms that point out to the same reality, I will further use

the term "*structures*" as it fits best my analytical scope. Initially, I wouldn't think of using this structural approach, but I argue it was needed as I witnessed strong, powerful and eventually constraining structures that would really circumscribe and frame the role of individuals within the research team I engaged with, as well as the role of this team in the overall R&D center.

This structural approach has a twofold added value to my case study analysis. Firstly, just as much as technology and society co-construct one another, it can be said that individuals shape and are shaped by the context in which their actions take place. As I followed individuals, it makes sense to pay careful scrutiny to the actual interplays between them and their organizational context. Secondly, structural approaches are a powerful tool to bring the politics back in. As I shall demonstrate, the R&D center I engaged with is in itself embedded in broader relationships with different kind of social actors, up to the point I couldn't deny it any further, let alone simply ignore it. These strong dynamics would obviously play a crucial role that is easily understandable in terms of politics. It is a way not to forget about context but also not to insulate the context from what is actually going on at the laboratory floor.

To conclude this part, SCOT as a theoretical framework holds still and I will definitely use it, also picking up elements from the EPOR program (focus on micro-situations, social interactions), from SCOT itself (one relevant social group, overall constructivist approach to nanotechnologies) and also some more structural considerations (importance of structures on individuals and even on research teams). This framework will allow me to address a particular technological artifact that belongs to the whole development of

"nanotechnologies". However, this term isn't unproblematic and deserves a lot of clarifications; it needs a strict delineation. Whenever I refer to it in my case study, it actually points out to a rather precise object that is actually loosely related to the nanoscale. So there is many precisions that one should be aware of before addressing this particular issue. The second section of this chapter will now introduce the term of "nanotechnologies".

2. On nanotechnologies

"Nanotechnologies" is certainly not a term to be taken-for-granted. It is widely used and misused and points out to multiple different realities, more or less precise artifacts as well as broader technological developments. I want to unpack this notion according to the constructivist approach I developed above. I will provide a loose yet official definition that frames the debate; point out the phantasmagoric dimension of nanotechnologies, which are fulfilled with great expectations and fears; give a clue of the manifold dimensions of nanotechnologies, explore heterogeneities rather than homogeneity. I will show how knowledge and technological development are so merged that one couldn't really distinguish one from the other anymore, even though it used to be possible until 2003. Before this turning point in nanotechnologies' short history, those two different perspectives (fundamental knowledge and material applications) would co-exist. This is no longer the case. I will then attempt at concluding this part by raising the question of what actually does the term "nanotechnologies" stand for, and I will fail to provide a satisfying definitive answer. I will then have a short "real" conclusion accordingly.

2.1.   A Tentative Definition of "Nanotechnologies"
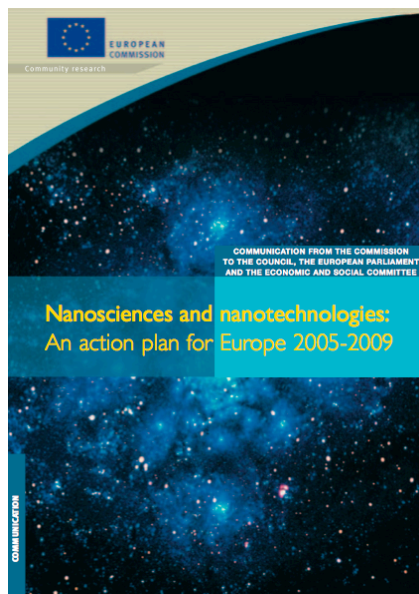
Nanosciences and Nanotechnologies are keywords that relate to an emerging scientific field, which is strongly expected to provide technological outputs. Originating from the Greek word for dwarf, the "nano" prefix signifies 10^{-9}, i.e. one billionth of a unit of measurement as a meter, a gram, etc. Roughly, "*Nanosciences and nanotechnologies (N&N) are new approaches to research and development (R&D) that concern the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale*" (EUROPEAN COMMISSION, 2005). This definition is twofold and it is important to highlight it. One the one hand, its first leg refers to a bunch of R&D issues tied with a particular scale of size. In this respect, the definition is rather classical and allows to frame nanotechnologies quite strictly, in terms of whether they belong or not to this knowledgeable scale, a strict technical category. On the other hand, and not all 'official'[9] definitions refer to it, the second leg insists on the novel properties of the matter at such a scale. This notion is infinitely more complex to grasp as it deals with the very nature of nanotechnologies. When applied, this criterion distinguishes the radical novelty of nanotechnologies – or the lack thereof. It may be of great importance, for instance for regulatory purposes. For example, the REACH directive from the European Commission includes specific rules for some

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[9] By 'official', I refer to public policies documents.

nanoparticles of carbon, since the specific particularities of carbon particles at the nanoscale that have been acknowledged. So, the definition of nanotechnologies is already twofold and this fracture line goes along manifold elements regarding nanotechnologies.

From the very beginning and the "founding fathers" of nanotechnologies, the emphasis was set on the radically new properties of the matter at the nanoscale, where would lie their whole scientific as well as technological potential. To detect (1981) and manipulate (1989) atoms at this infinitely tiny scale was made possible by the development of a very precise technological instrument, the scanning tunneling microscope (STM – for a balanced account on the history of nanotechnologies, see SHEW 2008). Nanotechnologies' pioneers had the sense that their research could lead to discover a new world, a very *terra incognita*, still far unknown, and contribute to a better understanding of the matter and the world we live in (e.g. JOACHIM & PLÉVERT 2006). Obviously, policymakers did not always promote this approach, more likely promoting an approach oriented toward R&D and material outcomes of innovation.

2.2. The 'Next Industrial Revolution'

Rather, the policy world in general mainly advertised the incredible outcomes one could expect out of nanotechnologies' development, especially in economic perspectives. The announced promises are numerous and highly put up front in any kind of general account about nanotechnologies: medical breakthroughs (nanosensors that could "smell", seek and destroy cancer cells, enhancing aged cells to have a better diagnosis of, and ultimately prevent, Alzheimer's disease),

cheap and clean energy, water-cleaning processes, or a global reduction of pollution by the reduction of raw materials needed for production, etc. A good example of this kind of breakthrough promises for tomorrow is the *National Nanotechnology Initiative* (NNI).

"*Nanotechnology: Shaping the World Atom by Atom*" is an ambitious report from the Interagency Working Group on Nanoscience, Engineering and Technology (IWGN, 1999) that preceded the NNI. It was released by 1999, at the very early stages of the worldwide spread of nanotechnology as a key sector for innovation, research and development. Its title describes accurately the agenda of nanotechnology as advertised by then: "*Shaping the World Atom by Atom*". Such an agenda has a proper revolutionary dimension that I would like to highlight through this following excerpt:

> *The emerging fields of nanoscience and nanoengineering are leading to unprecedented understanding and control over the fundamental building blocks of all physical things. This is likely to change the way almost everything—from vaccines to computers to automobile tires to objects not yet imagined—is designed and made.*
>
> *If you were to deconstruct a human body into its most basic ingredients, you'd get a little tank each of oxygen, hydrogen, and nitrogen. There would be piddling piles of carbon, calcium, and salt. You'd squint at pinches of sulfur, phosphorus, iron, and magnesium, and tiny dots of 20 or so chemical elements. Total street value: not much.*
>
> *With its own version of what scientists call nanoengineering, nature transforms these inexpensive, abundant, and inanimate ingredients into self-generating, self-perpetuating, self-repairing, self-aware creatures that walk, wiggle, swim, sniff, see, think, and even dream. Total value: immeasurable.*
>
> *Now, a human brand of nanoengineering is emerging. The field's driving question is this: What could we humans do if we could assemble the basic ingredients of the material world with even a glint of nature's virtuosity? What if we could build things the way nature does—atom by atom and molecule by molecule?*

> *Scientists already are finding answers to these questions. The more they learn, the more they suspect nanoscience and nanoengineering will become as socially transforming as the development of running water, electricity, antibiotics, and microelectronics. The field is roughly where the basic science and technology behind transistors was in the late 1940s and 1950s.*

> **Interagency Working Group on Nanoscience, Engineering and Technology, 1999, p. 1.**

In other words: scientists learned how to deconstruct the world up to its tiniest scale, now they face the incredible challenge to re-build it, as nature does, using its own elementary building blocks. The ambition of this report is to reshape the world we live in, atom by atom, no less. Two main lessons can be learned from this excerpt. First of all, it has a genuine revolutionary dimension that would be further emphasized in the NNI, as I shall mention later on. One may see manifold entangled issue here: human control over nature, absolute design abilities, a fully technical handling of dots of matter up to the atomic scale, and the like. This agenda, if pushed forward, would lead to sort of human-created, autonomous devices and mechanisms that would perform about every possible task one could ever imagine, somehow paraphrasing '*nature's virtuosity*'. A second lesson lies in the framing in terms of '*value*'. It is not clear what is actually referred to when the report states that an '*incommensurable value*' is no longer out of reach. Tied as it is with the function of "nanoengineering", one might be tempted to understand this idea of value in terms of engineering nano-enabled artifacts and, by extension, reaching new markets and economic outcomes. This interpretation of the report is of course not to be taken for granted and stands for no more than what it is, namely an interpretation. Still, I argue (with JOACHIM & PLÉVERT, 2008) that this particular vision of the '*value'* of nanotechnologies' development and of its revolutionary potential, especially understood in terms of economic

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outcomes, is largely salient in the *National Nanotechnology Initiative* (NNI, 2000 & 2004).

Of course, these elements have to be understood as an ambition, an important expectation that nanotechnology will deeply affect the world we live in. Vinck strongly questioned this revolutionary perspective. He disambiguates what is genuinely revolutionary from what is a merely incremental change. He argues that most of nanotechnologies' developments actually modify actual ongoing production processes and artifacts only at the margins. Whatever might be revolutionary about nanotechnologies would exclusively deal with long-term perspective and would need to be considered in combination with manifold different technological developments that together – and only together – are likely to change deeply social structures, perform human enhancements or, say, revolutionize production processes (VINCK, 2009, pp. 29-35).

2.3. A strong, though controversial, public uptake on "nanotechnologies"

I argue nobody could have a clue of the overall research ongoing under the label "nanotechnologies". Over years, the idea of a single, hegemonic, one-size-fits-all "nanotechnology", disaggregated itself into what some authors called 'a plurality of nanotechnologies' (BARBEN & AL., 2008). This certainly refers to the high variety of actual scientific and technological developments. One thing is certain: whatever is referred to when using this word, public authorities strongly push forward these developments. Interestingly, in public policies documents, they would increasingly use the heterogeneous "nanotechnologies" rather than the

single "nanotechnology" (for instance, see EUROPEAN COMMISSION, 2008). This reflects not only upon a quantitative statement (the wide variety of applications), but also on a more qualitative one, namely deeper uncertainties and complexities that arose in the nanotechnologies case. I will now try to show both the dual reality of a strong commitment from public authorities when it comes to promote nanotechnologies, balanced with an overall context of public controversies and fear of public opinions' reactions. This, I argue, results from this irreducible "uncertain" side of nanotechnologies.

The first thing to highlight is the strong interest of policymakers worldwide in nanotechnologies' development and the very important subsequent funding. The interest of policymakers in the development of "nanotechnology" came first from Senator Al Gore' "*Science in the National Interest*", a report released in 1994. Following this, strategic plans were adopted in order to launch nanotechnology programs and not to be distanced by other "technological zones" (BARRY, 2006). This idea of technological zones refers to different geostrategic areas, which are involved in a commercial competition on the global scale. These are salient in a global landscape where competitiveness is envisioned as a key issue for governments. In this respect, the Japan Government has been involved in this crucial issue since 1992 (*Atom Technology Project*), but the first massive public investment initiative originated from the USA, with the National Nanotechnology Initiative officially launched in 2001. This program was granted $ 300 millions, growing every year until it reaches a provision of $ 1,6 billion for 2010. The European Union funds nanoscience and nanotechnology through its "Nanosciences and nanotechnologies: an Action Plan for Europe 2005-2009"

(EUROPEAN COMMISSION, 2005), with a public budget of about € 3 billions. Nanotechnologies take benefit of important investments from public authorities.

However, from its very beginning, the development of nanotechnologies has been hugely controversial. Typical of it is the existence of various and multiple controversies in the public sphere, complemented from time to time by the expectation of such controversies to occur, from both policymakers and nanotechnologists. This is clearly related to the case of biotechnologies, whereas strong public controversies happened, especially about GMOs. So, from the very beginning, numerous actors claimed for lessons to be learned, from the biotechnologies development example (DAVID & THOMPSON, 2008). Combined with the popularization of dystopian imaginaries (as in Michael Crichton's novel, *Prey*, see below point 2.5.), this eventually led to a fear of controversy and a political willingness to prevent them by any means. As Rip nicely put it, nanotechnologists do now fear public reactions and project this fear onto the public. Doing so, they interpret the way the public is likely to behave and raise troubles, express irrational (or uninformed) fears about nanotechnologies. "*Thus, the concern of nanoscientists and technologists about public concerns (painted as a phobia about nano) drives their views, rather than actual data about public views*" (Rip, 2006: p. 358). This, Rip calls it a "nanophobia-phobia". I argue Rip's point perfectly holds still when it comes to policymakers.

In short, one may easily detect a paradoxical injunction of developing, funding and promoting nanotechnologies as a strong lever of public action and wealth creation, on the one hand, and the fear of massive public controversies on the other hand. This fear is actually not all of a fantasy, as the recent events in

France showed sufficiently. I think this example deserves a little more details, although the France case should not stand for all the different national situations, initiatives and even political cultures. France's government mandated a Commission, the *Commission Nationale du Débat Public* (CNDP), to issue a debate about nanotechnologies. Beforehand, it initiated some projects on its own, as for example the funding and development of Minatec, near Grenoble, since 2006. In May 2009, it launched its "Nano-INNOV" plan funded up to 70 millions €. As the first European pole of nanotechnologies, this important research facility positioned France as the 5th player on the global nanotechnologies scene[10]. Then, the government decided to launch a public debate. As the Minister of Environment pointed out at the official press conference launching this debate, it was not a matter of principle, of saying "yes" or "no" to nanotechnologies. It was rather a matter of highlighting the general options available as for nanotechnologies' development and regulation, as states the CNDP "letter of mission" endorsed by no less than eight France ministers. A particular commission decided to bring up an ambitious setup for a wide event[11], with no less than 17 debates held either in Paris or in the "province", all around France, over a quite long period of time. From this moment in time started a very strong opposition to nanotechnologies, fueled by a local association of citizens called "Pièces et main d'oeuvre" (PMO). Different attempts to conciliate their quite radical views on nanotechnologies were made, involving methodologists and social scientists, in a participatory approach. These were dismissed by PMO,

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[10] According to the official communication of V. Pécresse, France Minister of High education and research, 5th May 2009.
[11] CPDP, « Débat public sur les options générales en matière de développement et de régulation des nanotechnologies », available online, http://www.debatpublic-nano.org/documents (accessed 2010-08-27).

which would argue that the actual goal of such participation was only to serve technocracy's ultimate goals and that social scientists would be, at best, lubricants to facilitate decision-making process, at worse, agents trying to shut down opposition on the behalf of the government (LAURENT, 2007). They would argue that the debate would occur too late (the nanotechnologies' strategic plan was already adopted; important investments had already been done; several hundreds of products containing nanoparticles would be already released on the market), and the debate was therefore politically misguided (by the will to shut down controversy). Eventually, through a thorough and noisy opposition, they prevented several debates from being held, leading the CNDP to invent baroque mechanisms for debating[12].

This rather funny story, even though probably typical of France, tells us something about how sensitive is nanotechnologies' development in public opinions and how governments find themselves trapped in this tricky paradoxical injunction. Funding while avoiding controversies; promoting but ensuring prudence and precaution; being in favor of outcomes but opposed to undesirable effects. In one word, public authorities are willing to embrace the "Next Industrial Revolution" and its huge promises, but yet they reject its potential perils and dangers.

2.4.   Beyond boundaries: A "profile of technoscience"

There is maybe a material cause of such a paradoxical position of public authorities. Namely, nanotechnologies would merge to an unprecedented extent

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[12] Such as debates through videoconference or locked-in debates in secret places displayed only to registered and formally invited participants, at the very last moment.

the production of knowledge and technological artifact. This is yet another element, which is crucial to keep in mind: it is rather difficult to disentangle nanoscience from nanotechnology. As I shall explain later on, most public funding is granted in order to provide concrete, commercially viable applications, while seeking to improve knowledge on particular issues tied up with the nanoscale. Usually, these two perspectives are qualified either as "basic" or "applied" science. That is, some scientists would preoccupy themselves with understanding basic phenomena as they occur "in nature", even the debate as whether this "state of nature" is actually a reachable target remains wide open. This question points out to deep and lively epistemological debates I already mentioned, initiated by Kuhn (1962) and Berger & Luckmann (1966). These cope with a very basic question: are we humans able to know reality, for instance at a molecular or atomic scale? The stake here is to determine whether scientists are able to actually come to grasp with the reality as such, by means of discovering things that exist independently of humankind. The epistemological alternative, considerably sustained by Thomas Kuhn's works and their further developments by fellow sociologists of science[13], consists in claiming that whatever reality does not exist on its own, but is rather always perceived through particular tools, scopes, methodologies, or abilities of particular humans in particular places (PESTRE, 2006; RIP, 1999)[14]. This view became widely popular in the field of *Science and Technology Studies* (STS), which preoccupies itself very much with the development of nanotechnologies.

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[13] Some caution is needed when it comes to the actual endorsement by those authors of any sort of epistemological relativism, especially regarding Kuhn who stepped back from further interpretations of his own theoretical thoughts (see RIP, 1999).

[14] For a more precise and fruitful account on this issue, see the introduction of Pestre (2008).

It is my contention that the field of nanosciences and nanotechnologies does not satisfy itself with too basic pictures like this one. For example, an author like Bernadette Bensaude-Vincent pushed the question further, up to the point of reaching a twofold conclusion on nanotechnologies. She argues that there co-exist striking different viewpoints on current developments:

> *"Clearly engineers and chemists have two irreconcilable views of nanomachines. So striking is the contrast that it raises the question: are there two cultures within the field named nanotechnology? In their revolutionary claims, Drexler and his followers never mention earlier attempts at taking inspiration from life. His emphasis on the bottom-up approach creates a discontinuity with more traditional materials processes. Moreover, thanks to the reference to Feynman, nanotechnology seems to be rooted in quantum physics thus proceeding from a 'noble' theoretical science rather than from 'dirty' experimental physics or materials engineering".* (**BENSAUDE-VINCENT, 2004**).

The traditional view of academic life endorses the huge divide between social and natural sciences, the famous "two cultures" of CP Snow (1964). One would assume that both engineers and chemists would have to be classified on the same side. Now, we learn from Bensaude-Vincent that engineers and chemists sustain very "irreconcilable views" of their respective nanoworlds. I could explore the divides and ongoing struggles further, contrasting electrical engineers' perspectives with biologists' ones, distinguishing one worldview from the other but it's not my point here. Enough is to show that nothing, when it comes to nanotechnologies, goes on too linearly or in any simplistic fashion. The lesson of this is the deep and irreducible heterogeneity of the developments, which calls for study-in-context. Most of the recent literature took the option, either way, to point out to this immense variety of situations, viewpoints, contentions, as well as the pressures for homogenization that are characteristic

of science (described by Latour & Woolgar in their seminal laboratory study, 1979). It does not make sense to refer to "nanotechnologies" as a single-sided development, as it might stabilize only in an unpredictable future in which procedures and machineries would be standardized enough, so that the human component is left aside (PESTRE, 2008). Only in this condition could emerge a strong enough consensus among nanotechnologists about the way nanotechnologies work. Still, the ongoing developments of this rather recent set of technologies do not allow, at this point, for such a global overview[15].

It is clear that a strict boundary between nanoscience and nanotechnology, for instance, doesn't hold still after an even basic analytical deconstruction. Actually, the division between the "scientific and "technological" does not make much sense, since nanotechnologies (at large, incl. nanosciences) do undoubtedly have "a profile of technoscience". To show that, I will draw on three arguments expressed by Bensaude-Vincent (2009b). First of all, even though nanotechnological developments occur at the nanoscale, one needs to take into account two very different approaches to nanotechnologies, which subtly blend industrial concerns with improved understanding of the matter, that is "applied" and "basic" science. I will go into more details and share an account about these mixed perspectives, as they are widely reported when it comes to nanotechnologies. Secondly, as this field bears with the matter at the molecular or even atomic scale, it has the exiting potential of a *terra incognita*, say good old fascinating science as it used to be. Still, at such a tiny scale which escapes the

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[15] I could even go further, by claiming that this intrinsic complexity and strong heterogeneity is not specific to nanotechnologies, and that actually must scientific developments as described as rather monolithic and straightforward, which they are obviously not.

common senses and human abilities of perception, one cannot but rely on very sophisticated tools and scientific instruments, as the scanning tunneling microscope (STM) or even the atomic force microscope (AFM). It does tell us that tools and discoveries are deeply intertwined, and that the illusion of a pure knowledge of natural facts is actually mediated by scientific instruments (even though it might be also the case for any kind of scientific developments – which is not the point here). Lastly, the boundary between science and technology is obviously blurring more and more. This proves especially true in the case of nanotechnologies. Researches in nanotechnologies are told to be increasingly oriented towards actual technological applications. According to Bensaude-Vincent, the universal constituents of the very matter, namely molecules and atoms, are thought about as machineries, or as functional entities than one could use and mobilize according to his will. In this respect, nanotechnologies are a very example of opportunistic technoscience, which aims at exploiting all the possibilities provided by the nanoscale through the use and mediation of technological artifacts. What matters are more the technical possibilities than the theoretical problems, the functions rather than a sound understanding of the structures (which behave differently at the nanoscale) (BENSAUDE-VINCENT, 2009b, pp. 609-611). In short, nanotechnologies definitely fit this "profile of technoscience" I already mentioned (ibid.).

Indeed, this conclusion suits very well an approach grounded in the SCOT theory. As a matter of fact, Pinch and Bijker themselves insisted on "How the Sociology of Science and the Sociology of Technology might Benefit Each Other" (PINCH & BIJKER, 1984). The merging of these two theoretical scopes that SCOT attempts to

achieve makes sense when it comes to an object like nanotechnologies, which in facts merges what comes from "pure" science or knowledge and what comes from the development of technological artifacts up to the extreme difficulty to disambiguate, or clearly identify, one side from the other. Hopefully, it is by now clear that the approach needed, when it comes to nanotechnologies, consists in an integrated framework whereas scientific knowledge and technological developments are understood as two deeply intertwined sides of the same issue, up to a total overlap.

2.5.   The history of a divide

As nothing goes unproblematic with nanotechnologies, yet another particular feature of nanotechnologies is the historical gap between two radically different perspectives in their elaboration. I do fully acknowledge the limitations of categorizing too much and the problems of over-simplification that may arise by doing so. That said, it is interesting to challenge a rather monolithic account about the history of nanotechnologies, because it further shapes my point of an irreducible heterogeneity. Shew pointed out to the different logical and mathematical steps that lead to nanotechnologies, from the inspiring speech of Feynman, the founding father, to the development of outstanding tools (STM, AFM) that would allow for navigating this exciting and yet unknown *terra incognita* (SHEW, 2008). There is two reasons for somehow deconstruct a bit the "black box" of the history of nanotechnologies. First, it is quite often the case that particular histories of certain technological development are re-wrote in a way that actually erases divergences, alternatives, choices, and that grants to

technology itself the sole merit of having been developed.

Think about the famous account from Bijker & Pinch about the bicycles I mentioned earlier. In their article, they point out to the multiple crossroads that influenced the development of the bicycles as we know them, preferences being expressed by social groups that shape options and further evolutions of the bike as an artifact (PINCH & BIJKER, 1984). In this respect, rewriting technological history raises the duty of putting up front the losers and forgotten ones of this history. The second reason to share an historical account on nanotechnologies, although probably too simplistic, is that this account is now particularly widespread and recognized as valid by the STS community (for a complete and yet very thoughtful analysis, see RIP & VON AMERON, 2009). Actually, it is one of the quite rare areas of relative consensus among STS scholars, which is worth mentioning and, undoubtedly, promoting a little bit, especially since the argument this historical account allows me to make is of importance: it contributes to show the contrasted trends and realities that lie behind the "empty signifier" term "nanotechnologies" (the expression "empty signifier is borrowed to WULLWEBER, 2008, see below).

From an historical perspective, nanotechnologies cannot be limited to a straightforward development path. Their history itself is mainly the one of a basic, sound divide between two main perspectives, both of them bringing its own values and expectations. Basically, the history of the nanotechnologies is the history of a deep divide between two communities (for an account "from the within" the community of nanotechnologists about this divide, see e.g. JOACHIM & PLÉVERT, 2008). The first side includes the partisans of the "bottom up"

approach, which consists in the construction of a new molecule from the scratch. They would envision their research as mostly fundamental and believed that this approach (building molecules atom by atom) would provide humanity with a greater understanding of the matter and huge savings in the use of raw materials, among others elements. This is a proper vision of what technological development ought to be and should be useful for. The promoters of this approach are rather idealistic scientists involved in a mere contribution to a body of knowledge for its own sake. One of those advocates of the "bottom up" approach was Erik Drexler, a leading scholar in the field of nanotechnologies, author of *"Engines of Creation. The Coming Era of Nanotechnology"* (DREXLER, 1986)*.* This book was popularized through the popular fear of the "Grey Goo" scenario (self-replicating molecules that would autonomously proceed to their own replication, turning everything into "grey goo" and eventually destroying the whole world). One may read Michael Crichton's apocalyptic novel, *Prey*, which describes this unstoppable invasion. This somehow "dystopian[16]" view (although very anecdotic in Drexler's overall positive appreciation of nanotechnology) happened to cause the public dismissal not only of Drexler's theories (the Grey Goo) but also of Drexler himself (RIP & VON AMEROM, 2009).

This public dismissal was actually undertaken by the very actors who became the mainstreaming representatives of the second side, who advocated a more "top-down" approach of nanotechnology. The key idea there was to carry on with further miniaturization of transistors and already known technological devices to a point where those artifacts would *de facto* reach the nanoscale. This was

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[16] As opposed to "utopian".

closer from industries' capacities and perspectives for a better-ensured return on investment. This view of technology was the one promoted and advertised by the US' *National Nanotechnology Initiative* (2001), with this strong uptake on innovation outputs I already mentioned. So, the (short) history of nanotechnologies is primarily the one of a divide, of a mainstreaming controversy (SHEW, 2008). This points out to yet another, primal and fundamental uncertainty, which underlines every debate one could sustain on the question of "nanotechnologies". Does one refer to a more fundamental understanding of the behavior of the matter at the nanoscale, playing around with new properties (the "bottom-up" approach)? Or does one rather refers to a more "business-as-usual" approach, industry-based understanding of the matter, whereas reaching the nanoscale is perceived as a next logical step, as a mere prolongation of the work provided before, yet another step in the long chain of scientific progresses? In short, here lies a second powerful fracture line along which it proves yet more difficult to define one single "nanotechnology" that would stand for all the others. I showed how loose actually are nanotechnologies' boundaries and how they are a typical example of technoscience, a term which by definition blurs the fundamental boundary between technology and science. Even cautiously as regards with over-simplifications, I then demonstrated to which extent the history of nanotechnologies is a contested one, made out of flaws and successes, of visions and strategies and even diverse expectations. In some sense, these elements remain stuck at a meta-level of explanation, an analytical perspective, which already envisions the nanotechnologies' phenomena through particular lens. So far, it might be that these elements lack

concrete examples and grounded illustrations of what nanotechnologies actually are. In order to clarify what is it actually that I'm talking about, I will have a word about some technological artifacts that undoubtedly fits nanotechnologies as they are rather than as they are thought of.

2.6.   *What actually does stand for "nanotechnologies"?*

Actual outcomes of the R&D processes for nanotechnology are yet far unknown and actually unlikely to be fully knowledgeable. Since nanotechnologies are totally out of reach for common human senses, they absolutely need to be mediated through the use of dedicated instruments like the STM, which makes them very inherently rooted with uncertainties and makes it hard for laypeople to have a grasp on what actually are "nanotechnologies". This happens especially at an early stage of development whereas people have no clue of the emerging patterns and dynamics of these new technologies. Most of the time, a technological artifact produces socially desirable outcomes while having undesirable, at least unexpected effects. Let's just think about something like the cell phone. On the one hand, it allows for new means of communication, for staying in touch with relatives worldwide, for loosely organizing social events or for reassuring worried parents. On the other hand, doubts are still cast on the potential harmfulness of cellular network's waves on human health, which brings local conflicts about antennas' location. It also revolutionizes the way we communicate, for good or for worse: there are obvious control issues, let alone deep troubles raised by privacy. New social norms arise and shape themselves in the course of releasing cell phones on the market and spreading it throughout

society.

It goes exactly the same way as regards with nanotechnologies. The French sociologist Dominick Vinck gives a rather inclusive and balanced account on all the different realities that lie behind the development of nanotechnologies (VINCK, 2009). In terms of consumer products, one may find nanoparticles in cosmetics, for instance to have a sunscreen penetrating through the skin membrane easier and more efficiently. More generally, chemical nano-powders are one of the main outputs of current developments that sustain industries' interest and investments. In the same idea, nanotubes of carbon are produced in increasing quantities. It so happens that carbon does have different properties that make it much more resistant at the nanoscale[17]. Alongside, multiple other developments occur. For instance, potential applications deal with improved solar captors that could be used for solar panels with a better return on investment. Applications in the biomedical field are numerous. To cite but a few, lot of ongoing research tries to reach more precise means of diagnosis; the next logical step, in this view, would be targeted drug delivery equipped with nanosensors that could select and erase infected cells while protecting or leaving unharmed the healthy ones. Another example lies in a combination of manifold technologies that have to deal somehow with the nanoscale, as they all together provide a "lab-on-a-chip". This label refers to a chip that is intended to deliver a fast and reliable diagnosis from any tiny biological sample. Potential applications already go beyond and further. For example, micro-implants or brain chips,

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[17] For a rather inclusive overview of consumers products containing nanotechnologies, see the PEN inventory: http://www.nanotechproject.org/inventories/consumer/ (accessed 2010-09-10).

including MEMS (micro-electrical-mechanical systems) or, in upgraded versions, NEMS (nano-electrical-mechanical systems). My case study will be about such kind of microchips.

A whole other area of research, undoubtedly rich with potential applications, is the military field of research. In the US, it attracts a significant part of funding, even though what precisely is being done within the framework of these programs remains largely unknown[18]. Once more, one should not condemn military programs as solely aggressive and potentially harmful ones as it is not that straightforward. Actually, a significant part of it is devoted to "defensive" applications that might find echoes in civil applications, for example in the biomedical field. So, here I pointed out to some of the actual realities hidden behind the word "nanotechnologies".

If one lets imagination take over, possibilities are suddenly endless and astonishing. Why could we not design nano-food whose taste may change according to particular present-time feelings? What about construction materials that self-fix themselves, whenever scratched or broken down? Or about self-constituting materials that could change their shape, forms or functions over time? Couldn't we build an elevator up to the moon using nanotubes of carbon? Have anyone ever dreamed of a computer made out of hyper-powerful nanoprocessors instead of outdate microprocessors? As a matter of fact, applications are potentially infinite, as well as their promises, their unintended side effects and, sometimes of course, their amazingly basic and naïve belief that

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[18] Informal discussions, CNS-ASU pre-workshop to the 1st S.NET Conference, Seattle, October 2009.

the world will change all over, no later than tomorrow. Most of the technological artifacts mentioned here are not good or bad by themselves, but none of them are neutral to society. Solving this question will strongly depends on whatever will actually come out of the manifold innovation process and, one step further, on whatever use will be made out of these artifacts.

Another tricky point, when it comes to nanotechnologies, lies in the fact that this term has played out the role of a buzzword – a purely marketing one. It is extremely difficult to insulate the specificity and the essential component that makes the singularity of a nanotechnological artifact. As Vinck put it, when it comes to define what exactly belongs to the nanoscale, to which precise component does one refer to (VINCK, 2009, pp. 13-17)? Is it enough than just one side or part of a product deals with a nanoscale dimension? What if a particular chemical solution enables reaction that occur at the nanoscale and that could even happen naturally, without any human intervention? Let's not forget that nanoparticles are to be found in the very nature as well, and are not necessarily the product of humankind. When it comes to label what is "nanotechnologies" and what is not, things get blurry. Again. It has been shown several times, and our fieldwork totally confirm this hypothesis[19], that "nanotechnology" is somehow an umbrella term, which has also been used for strategic purposes, in order to attract some public funding for example. This way, quite a significant amount of what is now called "nanotechnologies" would fit previously ongoing works and wouldn't need this specific labeling. Wullweber coined the expression "empty signifier" to illustrate the potential emptiness between a strongly

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[19] One of the researchers I engaged with blankly put that in.

promoted hype-word. Thus, according to him, "*the empty signifier nanotechnology serves as a techno-socio-economical innovation strategy*" (Wullweber, 2008).

I now find myself quite embarrassed as it comes to actually conclude this part, as I proved unable to precisely define and circumscribe what is actually meant while referring to "nanotechnologies". So the conclusion will be short. One thing comes out of all these developments for certain: there is no such thing as "nanotechnology", not even something like straightforward, unidirectional nor unproblematic "nanotechnologies". Rather, this field of applications that is deeply intertwined with the production of new knowledge at the nanoscale, is deeply heterogeneous. The variety of developments needs to be underlined further. Often advertised as "the Next Industrial Revolution", nanotechnologies are massively supported and funded by public authorities. That said, this leads to a great deal of controversies because of the potential harms of flaws of these evolutions. I will unpack these controversial elements a little bit more in the next part, in order to justify the interest and added value of my case study. Beyond the classical "science" and "technology" categorization, nanotechnologies really blur this boundary, merging into a distinctive, tough not unique, technoscientific development. One understands this better while browsing through the complex, divided history of nanotechnologies, and struggles that opposed different visions of their development. All of this, I argue, definitely suits a constructivist approach and makes the plea for a greater contextualization of nanotechnologies as I intend to provide with my case study. If I am to analyze the variations of technological development in terms of "interpretive flexibility", then I should

find myself comfortable with such a flourishing case study on nanotechnologies, marked by the emergence of multiple paths and the endless rising of manifold options.

3. On the value of the concept of "interpretive flexibility"

In this part, I combine all these elements about nanotechnologies with the theoretical framework I established in the first place, or rather its most recent extensions. I here intend to provide my fieldwork with a *rationale* and establish its political relevance. The kind of study I conducted is timely, as regards with actual ongoing developments. To demonstrate it, I first address the overall policy trend toward "responsible innovation". Then, I try to unpack this loose notion and dig a little bit deeper into its actual content. This way, in a third part, I argue that these elements can be fruitfully combined with a SCOT approach, especially with a one that deals with the particular concept of "interpretive flexibility", adapted as it is to my case study.

3.1.   Responsible innovation and integration

Over last years, a significant amount of public policies regarding nanotechnologies claimed for a "responsible innovation". It is not yet clear what is actually meant through this language element, but it certainly refers to an innovation process that somehow proves to be pervasive to broader societal concerns. As a matter of fact, it represents a significant evolution of policies discourses (RIP & VON AMEROM, 2009; FISHER & AL., 2006; BENSAUDE-VINCENT, 2009). For instance, it is to be found in both the US (US CONGRESS, 2003 – *21st Century Nanotechnology Research and Development Act*) and in the EU (EUROPEAN

COMMISSION, 2008 - *Recommendation on a code of conduct for responsible nanosciences and nanotechnologies research*). It rather testifies a political intention rather than a strictly defined agenda that would only need to be implemented. This commitment may be the beginning of a broader trend toward greater inclusiveness of innovation processes. By a loose analogy, one could see the same kind of evolution than with the STS.

The overall history of STS actually started with a strong political commitment, an academic response to the political and environmental contestations of the 1960s and 1970s. By this time, "STS" research, even not labeled as such, was ongoing in many places and different forms. The first attempts to bridge together those works under the acronym STS, that would then stand for "*Science and Technology in Society*", was better characterized as a "movement" (CUTCLIFFE & MITCHAM, 2001, p. 2). The very fuel of this movement was what Cozzens called "STS, The Problem", that is the basic underlying assumption that, broadly speaking, "*science and technology are in society, and that they do not sit comfortably there*" (COZZENS, 2001). Afterwards, STS, rather understood as "*Science and Technology Studies*", was further structured into a proper academic discipline, with different political agendas or research avenues made explicit, theoretical programs, critiques and other improvements.

In the same way, I stress that the whole policy idea of "responsible innovation" deals with the underlying assumption that something goes wrong with innovation, that innovation processes "*do not sit comfortably there* [in society]", to paraphrase Cozzens. One may argue that in the couple of next decades, this idea of "responsible innovation", which is so far a mere slogan, a simple

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recognition of some "problem" with technological developments, may evolve toward more and more structured political means aiming to define "responsibility" and ensure the actual compliance of innovation actors with this new imperative. The idea would be to find answers or solutions for these problems, which lack sound understanding from policymakers and clear formulation or identification.

Then, how to study these politics of "responsible innovation"? I shall now rely on a multi-level framework to address these tied but yet different issues. As this part is more about politics, I refer to recent theories on governance that acknowledge the need for a multi-level analysis. This way, it becomes possible to identify different layers of political action, while not insulating one institutional actor, neither a single public policy nor even a single actor. It rather allows for differentiating these different levels of action, while reflecting on the actual articulations between these, though this happens across different analytical perspectives. The idea of multi-level frameworks originated with studies in European integration in order to understand the complex interplays between the European Union institutions, member states and different other public authorities, e.g. municipalities. It addresses every possible kind of institutions, either generalist or specialized (MARKS & HOOGHE, 2004) and is made on purpose to include informal networks in addition to formal institutions (HOOGHE & MARKS, 2003). The notion of multi-level governance is already developed within the framework of evolutionary economics in close relationship with the complex notion of "institutions" I mention above. This framework operates at a macro-, meso- and micro-level. In this view, "*Micro is individual choice, and macro is its*

aggregate consequences. The sum of micro is macro, and the decomposition of macro is micro" (DOPFER & al., 2004, p. 264). From micro to macro and vice-versa, "*the upshot is an ontologically coherent framework for analysis of economic evolution as change in the meso domain - in the form of what we call a meso trajectory*" (ibid., p. 263).

Science policy or STS scholars specifically translated this multi-level perspective (macro, meso and micro), in order to cope with technological developments. I refer in particular to two different approaches that are rooted in the SCOT theory. Each tries to push the constructivist agenda forward, challenging and dealing with technological developments as they occur. These two approaches try to deal with societal implications of emerging technologies and therefore their embedment in society, while their development occurs. They assess technological developments "in-the-making". The first one is the *Real-Time Technology Assessment* (RTTA – GUSTON & SAREWITZ, 2002) and the second one is the *Constructive Technology Assessment* (CTA – SCHOT & RIP, 1997). The latter insists on the idea of "socio-technical developments" under the form of paths, co-constructed by social actors and technical artifacts, as "subsequent developments create new patterns" (RIP & TE KULVE, 2008) that stabilize over time. The approaches of RTTA and CTA are both rather recent and share the feature of calling for broader "integration" of societal and technical considerations. Over years, there have been numerous attempts at opening up technological innovation processes and policies, for example through public participation or stakeholders consultation. So far however, these attempts were often disconnected from actual ongoing developments, so the RTTA and CTA

approaches claimed for a better integration of different kind of societal concerns with technological development. In a way, they argue for bridging together social sciences and natural sciences, including their material outcomes.

My approach will be grounded in RTTA and CTA central tenets. It is not something extraordinary when it comes to nanotechnologies. Influent research centers on HES and ELSA issues of nanotechnologies rooted their research agendas in RTTA or CTA principles (BARBEN & AL., 2008; MACNAGHTEN & AL., 2005). In particular, the work provided by the *Center for Nanotechnology in Society* at Arizona State University (CNS-ASU) develops and pushes forward the agenda of the "anticipatory governance of nanotechnologies" (BARBEN & AL., 2008). My thesis walks in these footsteps, especially about the concept of "integration" (of socio-technical concerns) developed by these authors. This concept works in a multi-level framework like the one I introduced above (FISHER, 2007). As for me, I will refer to the macro-level at the level where policy mandate and discourses occur, as well as broad societal issues. Micro-level will be tied up with individual practices of innovation, which supposedly resonate in some way with the macro-level (in both ways, from micro to macro and from macro to micro). These relationships I will try to clarify throughout my case study. The articulation between these two levels of analysis is provided by meso-level trajectories, which I argue are embedded in institutional actors as R&D centers of academic laboratories. These institutions are constantly at the interplay between the individual researchers that compose them (micro-) and a whole lot of broader social groups, aka policymakers, end-users or industries (that all together shape the macro-level).

This concept of "responsibility" needs some further clarifications in terms of its actual meanings when it comes to nanotechnologies. Societal stakes have been successfully classified into two different sets of issues. One must keep in mind that these classifications are only useful tools to clarify the debate and should not lead to actually insulate those issues from ongoing technological dynamics, since it is widely acknowledged within the STS community that the outcomes of these developments, namely technological artifacts, embed these meanings and issues in their very design.

3.2.   HES and ELSA issues

These issues that bear with the consequences of nanotechnologies' development are best known as HES and ELSA issues (on these issues, see RIP & VON AMEROM, 2009; VINCK, 2008; BENSAUDE-VINCENT, 2004, 2009B & 2009C). HES stands for "health, environmental and safety issues". It relates to all the potential issues that deal with potential harmfulness, undesirable effects of particular nanotechnological artifacts. For example, health is at stake in the case of nano-cosmetics. Nanoparticles in a sunscreen better penetrate the skin, but what if they make their way forward inside the body. The same issue is raised with different kind of nanomaterials that raises the spectrum of the asbestos scandal. Another issue is the environmental one. Nanotechnologies may enable better solar cells or allow for desalination of seawater, but what becomes of them once they're released throughout the environment? Another example: an experiment lead by social scientists from the *Center for Nanotechnology* in Society at Arizona State University dealt with "silversocks". These socks contain nanoparticles of silver. At the nanoscale, silver delivers anti-bacterial properties. One could

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wear the same socks for one week in a row without any bad smell, with clean feet. But the study pointed out – among other things – the total lack of risk assessment when it comes to release anti-bacterial particles in the nature. These HES issues are presumably easier to handle through the traditional scientific methods. It is possible to create risk models, run experiments and simulate real-life situations in order to assess the actual harmfulness of a nanotechnological artifact. Yet, such studies meet two shortcomings. First of all, it often takes quite long processes, life-cycle analysis and so on, to determine best the consequences on the long run. The overall context of strong competition among nanotechnologist doesn't allow much for taking such a time. Secondly, on a relative basis, quite few financial means are devoted to HES issues. An overall of 5 to 6 percent of the public funding deals specifically with these stakes.

Another set of issues consists in the ELSA ones. Those stand for the ethical, legal and social aspects of nanotechnologies. The ethical issues, though loosely defined, refers more or less to values judgments as whether a technological development is good or bad or, to put it otherwise, is worth developing further or not. For example, is the development of brain implants socially desirable or not? The legal issues are more likely to be tied up with fundamental human rights as they are guaranteed by several international dispositions. This is especially true at the level of the Council of Europe and the Universal Declaration of Human Rights. That said, much more legal issues are raised by the development of nanotechnologies, as the question of intellectual property. For instance, end-of-pipe artifacts are more and more often the fruit of extended international collaboration and result in the sharing of much expertise and

facilities, equipment or materials. Lastly, the social issues refer to shifts provided by new technologies to the modalities of the vivre-ensemble. In the case of nanotechnologies, it is yet unclear as to whether actual applications may fundamentally question social norms and establish new ones. Still, it is worth mentioning the example of nano-enabled diagnosis tools or brain implants. In the long run, such tools are expected to provide means of curing diseases and may therefore contribute to an ageing society. The point here is not to determine if ever such an evolution is socially desirable, but rather to highlight a potential demographic evolution that would then come along with a whole set of consequences (see FUKUYAMA, 2002).

In this part, I embraced the perspective that what really matters is not much what one may call "nanotechnologies", but rather the very consequences of their development, classified as they are in HES and ELSA issues. Through all these elements, I intended to provide an accurate overview of all the potential diversity and variety of nanotechnologies' effect on society, which are of political significance. It is my contention that all the clarifications and elements provided so far were actually mandatory in order to go further with a proper inquiry. It is now time to make arguments, raise issues, ask questions and hopefully provide bit of answers.

3.3. Henceforth, rationale for engaging a R&D Center

So, I addressed to macro-narrative of "responsible innovation" and tried to provide an understanding of what it means, in terms of both HES and ELSA issues. Of course, all these perspectives are located at a macro-level, whereas

broad societal and policy trends operate. The mandate for "responsible innovation" is an umbrella concept, which supposedly deals with every single kind of innovation actor, from large-scale R&D centers to small academic laboratories or technological startups. These operate within that evolving political context but at a different level, which might turn out to be totally disconnected from this political agenda. I rather intend to "connect" actual practices of innovation with this repertoire of political discourses. For this purpose, I draw on Fisher's approach of "socio-technical integration", which is especially relevant also because nanotechnologies are, so to say, in their infancy:

> *While early stages of innovation are thought to afford greater degrees of freedom, they are also characterized by deep uncertainty. Only during later stages of development, when investments have been made and interpretations stabilized, do socio-technical outcomes begin to become more clearly identifiable. The "control dilemma" thus implies that anticipatory and other "midstream" approaches may be viable alternatives to traditional command and control attempts to direct technology from the outset or to regulate it after the fact. This has occasioned renewed interest in early socio-technical integration sites such as laboratories. While the role of the micro-level is limited, laboratories set many of the initial conditions for knowledge production, diffusion, and transformation. They help codify material practices and, to some extent, thereby inform the behavior of meso- and macro-level institutions populated by technological actors.*
>
> **Fisher, 2007, p. 157.**

To make my point clear, I follow Fisher in that idea that laboratory studies are timely when it comes to nanotechnologies, because they are still at an early stage of development that allows for flexibility. While broad research orientations have been provided, end-user products are not yet released on the market. Rather, prototyping stage is still in the making and determinant orientations are to be taken within the next few years. It is important to understand that the

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point here is not to assess to which extent the imperative for "responsible innovation" is actually implemented among institutional actors at the "meso-level", but simply to underline the existence of such a policy mandate. I will not scrutinize laboratory practices in order to find traces or clues of the implementation of such mandate. That said, this overall context is out there and needs to be taken into account, partly because it legitimizes – or provide a *rationale* for – the actual engagement of innovation institutions by social scientists.

Based on the issue I addressed in the second part of this chapter about nanotechnologies, we now see to which extent nanotechnologies are difficult to apprehend as an object of research on its own. It is actually inter-connected together with multiple social realities and technological artifacts. I argue than a too-narrow scope on a nanotechnological artifact could not restitute faithfully the bigger picture and underlying dynamics of it. Henceforth, I will rather address individual practices in order to provide concrete and meaningful illustrations of how artifacts are designed, and all the variations of this process. There is a duty to understand technoscience in-the-making, taking into account scientists or engineers' viewpoints and daily routines, otherwise it remains pointless to normatively state or claim for better societal embedment of emerging nanotechnologies. One mustn't, I argue, disconnect his statements from actual practices but rather challenge them, trying to have a grasp on them even from a purely technical perspective, in order to better understand precisely how to (re-)connect them with different sets of concerns. For example, the pragmatic limitations of deliberative action and public participation exercises

were made clear in the case of the *Human Genome Project* (HGP). This project would lead to an abundant literature and a great deal of public participation, which would eventually contrast the few actual outcomes of the project in terms of engaging actual socio-technical developments, given its large scale and means (FISHER, 2005). All of this provides the *rationale* for engaging a particular R&D center on the level of micro-practices. As I discussed in the first part of this chapter, while this approach is genuinely constructivist, it borrows from the empirical program of relativism a focus on very situated, local sites of inquiry.

Chapter 2: For a contextual approach to nanotechnologies: a STS perspective on a R&D center

So, we learned from the first chapter that I intend to provide a sound understanding of nanotechnologies as they are developed in a particular context, from a constructivist perspective. I elaborated quite a lot on all these elements because I do think it is important to precisely circumscribe what nanotechnologies are about and what they are not about. This constructivist take allows me, also relying on the EPOR, to look more in details to actual practices of designing and shaping a certain nanotechnological artifact in-the-making, in order to trace its possible variations and eventually its interpretive flexibility. Though I shall point to many clues that such variations actually occur, my findings also call for greater contextualization in terms of structural perspectives, as I already mentioned. In this chapter, after I explained how and when the study was conducted, I introduce imec, a leading R&D center in Flanders, Belgium, as well as the team I engaged with. Then, I share different stories that make the case for different kinds of interpretive flexibility. For this purpose, I focus on micro-decisions of individual researchers, all of them being included in the same research team (doing so, I follow FISHER'S & AL. approach, 2006). For instance, researchers in their daily routines and practices keep on making choices, on deciding to go this way rather than this one, etc. They inform their decisions with manifold considerations, among which practical, cultural, epistemological or strategic ones. I will reflect on this by sharing four different stories that shows different research choices, which might to actually matter in

terms of technical outcomes out of the innovation process.

The following study took place in a large R&D institution located in Leuven, Flanders, Belgium. It was conducted between February and June 2010 with a presence *in situ* ranging from one up to two days a week. During this period, three different, though overlapping methodological approaches were undertaken: formal semi-structured interviews, embedded within a more general ethnography, as well as multiple informal interactions.

Firstly, formal interviews were scheduled and conducted. The research team manager was interviewed twice, once at the beginning of the study and once at the end. Every researcher of the team (sixteen interviews in total) was interviewed in the two first weeks of the study. From these preliminary interviews, I elaborated a symmetric setup in order to make sure the four researchers I would further interact with have a complementary profile. Also, each of these researchers was willing to engage in the study. With those 4 researchers, I conducted formal semi-structured interviews, in order to unpack the choices they make, according to which considerations, the possible alternatives as well as the actual outcomes of these choices. Two of these four were Senior researchers. With them, I had about 5 semi-structured interviews over the 3,5 months of the study that is one in every two or three weeks (depending on their availabilities). The two others were Junior researchers who I interviewed on a weekly basis (about 10 interview each), also with this semi-structured frame. From a week to the other, these interviews would allow a follow-up of different issues, understood in the form of research decisions that

would turn out to be a rather iterative process.

In order to deal with this important amount of audio material, I proceeded to partial transcription. Ideally, an interview should be integrally transcribed so that a selection of relevant points could be done easier, straight from the paper. Yet, I argue that computer software offers new means to proceed to such a selection, offering a better trade-off in terms of the time consumed by an integral transcript. Therefore, I proceeded to the partial transcription of the interviews using a piece of software called "Transcriva"[20]. Thanks to this software, recordings could be transcribed under the form of a conversation, allowing to identify different interlocutors and also to add annotations.
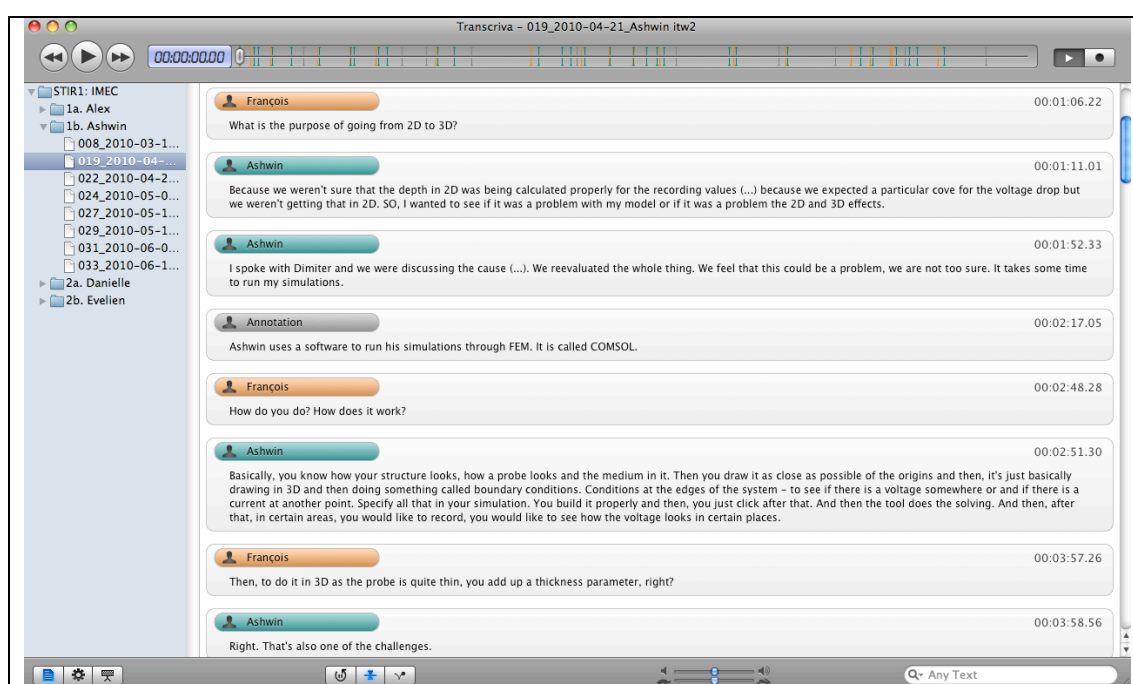
Fig. 1: example of partial transcript. The software keeps tracks of the exact timing, allows to browse easily

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[20] This process of identifying the good method to deal with the important amount of data generated took quite a long time, and I am personally very happy with all I could get out of this software, which is both faithful to the content of the tapes (it is rigorous and demanding) and flexible at the same time (it doesn't frame too much the way segments are categorized, labeled, tagged and eventually, locked in narrow frameworks). In that sense, it is a good trade-off between a "research" labeled software, which proved awfully inefficient at making sense out of recordings and handwriting notes which were very good at it though very difficult to handle, spread, share and discuss afterwards.

Secondly, all these interviews would take place within a more general ethnographic approach to imec research facilities. It is mandatory to provide as many observations as possible as they enlighten and contextualize the data resulting from all the semi-structured interviews. For this purpose, I followed the seminal approach of laboratories' ethnography as it was initiated by Latour & Woolgar (1979). Through deep observation, they established the "social construction of scientific facts". They showed how scientific instruments were used to "translate" a specific perspective on reality that was further translated through different stages of interpretation of this data, up to the point of a simple graph that would stand for all these preliminary stages of translation. To make this point, Latour & Woolgar would perform thick descriptions of the laboratory environment, paying attention to each and single detail that might matters. Following this example, in order to complement and surround my interviews, I basically observed every element I could and faithfully handled a notebook (two, actually), which now contain more than 250 A5 pages of notes. These are about conversations I had with researchers, of course, but also about the environment. It includes various elements such as imec documents, reports or newsletter, different informal statements (notably some of them made nearby the coffee-machine corner), attention to the configuration of working spaces, infrastructures or facilities, expressed feelings, the amount of events organized at imec, etc.

Lastly, obviously, there was a lot of informal interactions as well, that were not

properly, scientifically handled – though I would always take notes about these whenever something relevant would pop up in these kind of conversations. My favorite example, which will turn out to be interesting at some point, was about the linguistic policies of imec. Though created by Flemish authorities, imec is now widely international. It hosts more than 50 different nationalities and English is obviously the official working language and a necessary condition to get hired there. Of course, this has strong implications on the use of Dutch among researchers, which tends to decrease more and more. Some are resisting this trend, but most are giving up. This of course generates frustrations and feelings of awkwardness that were occasionally expressed to me through one or the other story, especially since Flemish political identity is so sensitive about the linguistic issues – that, in this case, would be dismissed for the sake of global competition.

4. Situating the case study

4.1. On "imec"

> "IMEC performs world-leading research in nanotechnology. IMEC leverages its scientific knowledge with the innovative power of its industrial partnerships in ICT, healthcare and energy. IMEC delivers industry-relevant technology solutions. In a unique high-tech environment, its international top talent is committed to providing the building blocks for a better life in a sustainable society.
>
> IMEC is headquartered in Leuven, Belgium, and has offices in Belgium, the Netherlands, Taiwan, US, China and Japan. Its staff of more than 1,650 people includes over 550 industrial residents and guest researchers. In 2008, IMEC's revenue (P&L) was 270 million euro".

Official company profile from website[21].

Imec is a large-scale R&D center that aims at performing world-class, state-of-the-art technological developments. The Flemish Government created "imec"[22] in 1984, as a non-profit organization. The goal was "*to strengthen the microelectronics industry in Flanders. The decision was inspired by the strategic importance of microelectronics for the industry* (…)" [23]. Obviously, it was the result of a greater political autonomy of the Flemish government resulting in important reforms of Belgium that would lead to the actual construction of a proper federal State by 1993. Nevertheless, by August 1980, important reforms of the State would grant autonomy to the regional authorities in all the domains related to economic issues. By this time, the Flemish government would adopt a rather top-down, "command & control" policy as for innovation. They would trigger technological development and put innovation at the heart of their economic model (GOORDEN & AL., 2008). So, imec has the goal to reinforce industry's development in Flanders, Belgium. For instance, one of its missions is the creation of spin-offs. Each year, imec is accountable for launching at least one of these. It also has to develop a lot of partnerships with Flemish companies (more than a hundred lately, for more than five hundred structural collaborations worldwide).

In general, imec strongly promotes and advocates collaboration within the framework of its open-business model. According to this business model,

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[21] http://www2.imec.be/be_en/about-imec/company-profile.html (accessed 2010-08-16).
[22] I shall write "imec" rahter than "Imec", since "imec" (without the major cap) is a registered trademark that has to be used in any kind of external communication, even when referring to any sort of imec prototype or product.
[23] http://www2.imec.be/be_en/about-imec/history.html (accessed 2010-08-16).

collaboration is to valued as such, and has to cross-cut boundaries across different teams, research cultures, epistemological perspectives, disciplinary backgrounds, and even – why not? – across the famous "two cultures" gap. For the sake of collaborating, even a social scientist like me would be welcome to engage and team up with an imec team and fellow researchers. I encountered very few problems to get introduced to imec and I was granted full access to non-secured areas, I could go and leave as I intended and very no restriction was imposed on me. The open-business model of imec is not an empty statement: it is rather a reality I could witness – at least in the research team I engaged with. It has the property of being genuinely inclusive, in this sense that every kind of perspective seems welcome, the underlying assumption being that each and every collaborator may have something to bring to imec, and that the costs of being inclusive should in any case be lower than the potential benefits.

With its large-scale organization, its huge amount of partnerships and this inclusive business-model, imec is entitled to ambition and doesn't fail to be ambitious. The overall mission they assign to themselves is no less than "building a better future". "*Imec aims to find solutions – with nanoelectronics – for the challenges faced by society in the coming decennium. These challenges include climate change and the depletion of the earth's sources (renewable energy), the ageing population and the rising costs of healthcare (biomedical electronics), sustainable mobility, efficient communication etc.*" ("imec at a glance [24]").

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[24] http://www2.imec.be/content/user/File/Brochures/Imec_at_a_glance_2010_EN.pdf (accessed 2010-09-10).

Imec now sustains three different umbrella research directions, three main programs that are: solar cells, energy efficiency and healthcare. Of course, these three main areas overlap and cross-fertilize one another. In Belgium, imec is spread over 4 buildings located in the campus of Heverlee at the Katholieke Universiteit of Leuven. These are equipped with important facilities, big cleanrooms and state-of-the-art instruments.

4.2. On the "cellular interfacing team"

The team I engaged with is involved in the "cellular interfacing" program. This "cellular interfacing team" is part of the larger bioelectronics group, itself located within the "bionano" department. The main focus of the team is biomedicine. It investigates issues of interfacing between cellular tissues and technological components, especially with the imec chip. This chip involves some nanometers (a few) and mostly some micrometers components. Still, it deals with phenomena typical to the nanoscale that researchers from the team try to deal with, understand and overcome. To achieve this goal, the team proceeds to both in vitro (on cellular samples) and in vivo (on animals) experiments, with a broad array of disciplinary perspectives (e.g. electrical engineers, chemists – either surface chemists or biochemists, biologists, proper nanotechnologists). The ultimate goal is to implant the chip in the brain without damaging it too much and then stimulate and record neuronal activity. Based on a sound understanding of neuronal activity, including inter-neuronal communication, the team expects to develop further capacities (drug or products to cure degenerative brain diseases) or products (chips equipped with further

functionalities to cure such diseases).

By the time I engaged the team, it had wonderful dynamics at play, three of which I shall mention. Firstly, the team I engaged with had strong ties with the Katholieke Universiteit van Leuven (KUL). In December 2009, its former research manager, Karen Maex, left the team for a Professor chair at KUL where she already had a position. For this reason, many PhDs in the team have been undertaken together with KUL (and through KUL funding), and strong ties still exist today. Secondly, a new manager who came from within the team, Wolfgang Eberle, had replaced her by the beginning of my inquiry. It was interesting for at least two reasons. On the one hand, he was hired on imec payroll and therefore was less tied with the University, and this would turn out to shape his scope about managing the team. On the other hand, Wolfgang had a strong political agenda he wanted to implement, knowing rather precisely what he intended the team to achieve. The team was on successful tracks and would keep on increasing, and he would try to sustain that dynamics. A third dynamics at play was a consequence of Wolfgang's appointment as a manager, ans consisted in actual reconfigurations of the team's organization, namely the merging of two "sub-teams", the in-vitro group and the in-vivo group.

I should elaborate a little bit on this last dynamics since it had important consequences in terms of projecting the team onto its future through the endorsement of a strategic roadmap, as I shall mention later on. The team formerly used to provide in vitro experiments, which is referred to by Wolfgang as the "classical way" of studying cellular interfacing. Yet, about 3-4 years ago, it launched an independent "in vivo" subprogram. The in vivo team was sort of

put into an "incubator", lead by a person alone at the beginning, then by a few people, so that it could acquire its own dynamics and catch up with the "in vitro" one. Eventually, once this step is accomplished, these two sides were to be reunited within the very same unit. I witnessed the beginning of this process, formally initiated with Wolfgang's appointment as the manager of the unit, in December 2009. This issue would lead to significant evolutions, such as a certain blurring of boundaries between the former groups, as well as new means of collaboration. According to Wolfgang, collaboration has been increasing and improving since a few years, as compared to what used to happen before. He found the rather artificial and top-down division between "in vitro" and "in vivo" teams to be useless at best, let alone counter-productive ("*you need not to feel like you cross a boundary when you collaborate*"). Wolfgang would promote a renewed, activities-based division, which would fluctuate depending on specific projects, circumstances or available expertise. Within such a framework, interactions would occur on a punctual and informal basis, rather than a strict and formal one.

I recorded many clues of this evolution toward the merging of the two "sub-teams" into a single one through. For instance, each of the groups still used to have and still has its own weekly meeting. Everyone is always welcome to the other's group meeting on a voluntary basis, and some, which work a little bit in vivo and in vitro, are even encouraged to participate in both. Initially, Wolfgang intended at scheduling a weekly lab meeting with both teams, but this initiative reached a shortcoming because of a lack of common topics to address and also because of the work overload caused by other meetings. It wouldn't prove to be

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strictly useful so it was cancelled. There is also a physical issue here, regarding the disposition of offices. Actually, the two groups used to occupy different floors. The "in vivo" group, which used to occupy the 1st floor, moved out to the 3rd floor and then joined the "in vitro" one, at the very beginning of my inquiry (about Feb. 2010). Obviously, the new setting of the offices brought about more exchanges and interactions between the researchers of the two groups – even though one could still notice more ties between the researchers of each group. This might change over time. The interesting point here is to keep in mind these dynamics of reconfiguration as they turn out to play an important role in terms of structural constraints thrown on individual researchers in the team, as I shall demonstrate.

4.3.   A symmetric setup

After I interviewed every researcher of the team, I selected four of them with whom I would interact further. I followed them during three months. This selection was operated according to five complementary criteria: membership to one of the groups (in vivo / in vitro), actual research position (Senior researchers on imec payroll, Junior researchers PhD from KUL), background (either more "linear" engineers or more "systemic" biologists), gender (male or female) to which I should add one criterion although irrelevant to this particular study, which is nationality (Belgians or foreigners).

Position / team	IN VIVO	IN VITRO
Senior researcher	*Alexandru*	*Danielle*
Junior researcher	*Ashwin*	*Evelien*

Background	Electrical engineering	Chemistry / Biology
Gender	Male	Female

Fig. 2: symmetric setup of the followed researchers*
* bold: five criteria according to which participating researchers were identified.

5. Individual choices shaping material outcomes – interpretive flexibility in practices

In each of these short stories, I shall unpack a particular research decision and explain to which extent it is relevant to the concept of "interpretive flexibility", therefore understood not as playing out among different social groups[25], as in the seminal SCOT approach, but rather as they play out at the level of the individual. Though very small and almost undetectable, I argue these research choices are important to understand, especially when it comes to the considerations that underlie them and which prove to have actual consequences in the eventual shaping of the chip. For each of these stories, I shall make a descriptive account of what I witnessed and what came out of my interviews with researchers, and then elaborate a little bit on its significance. Each of these stories comes from one of the distinct interviewees I followed more particularly.

5.1. Using DoE: an epistemological framework

In this case, an electrical engineer needs to play around with multiple parameters, in order to find the best combination of these for implanting the

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[25] I should make clear that I do not dismiss Pinch and Bijker's notion of social groups as relevant, but simply that I adopted a different scope, closer to EPOR locally situated empirical study which fits micro-inquiry as I provide here.

microchip into the brain without damaging the brain tissues. To find out, he would run in vivo experiments. Together with a biologist that would proceed to brain surgery, he would implant the chip and record the electrical signals provided by the neurons, in order to evaluate the damages caused by the implantation of the chip and predict in which situation the less damages are to occur. It would assess four different parameters for this purpose, in relation with the force needed to implant the chip: 1) the thickness of the chip, 2) its width, 3) its angle (the actual sharpness of the chip) and, lastly, 4) the speed with which it gets implanted. He would play around with these four parameters all at once, as opposed to the traditional scientific method that fixes all parameters and varies only once at a time. Let's illustrate how it does matter. If one needs to vary along four different parameters, ideally one should provide 4^4 experiments (potentially 256 total). It of course takes a lot of resources, both time and money, especially in a context whereas perfect repeatability of experiments is "*impossible to reach*" [26].

To this researcher, it was "*a completely different approach than typical research approach*". He was able to proceed in such a way through the use of a piece of software called "Design of Experiments" (DoE). It is actually a translation into software of an older method that originated in Japan. For all the different parameters to test, different scales are encoded in the software. Then, the software would automatically calculate appropriate coefficients, sort of "optimal" points, so that the amount of experiments to run could be significantly

[26] Although rats are aged the same and from the same species, each is a different biological organism; plus, experiments are run on the two different brain hemispheres and variations occur with surgery procedures.

reduced to 46 (instead of potential 256), by experimenting only on these "cardinal" points (only min. values, max. values and medium values for each parameters, and combination of these). "*The software can select only half if the experiments if you don't have the time or the money*". According to this researcher, not only it would avoid wasting resources but it would as well be more inclusive so that eventually the combination of parameters would be more efficient.

What comes out of this way to deal with a multiple-parameters setup is, of course, this rather strong **epistemological** uptake on a systemic perspective, rather than on a linear one. Instead of "local optimums" that would provide a traditional one-parameter-at-a-time, this more inclusive approach would supposedly guarantee the best combination of all parameters at once. This statement was strongly endorsed by this researcher. It was for him a way to avoid being "*less ambitious and try less experiments*", and still avoid as well to "*do more experiments for less value*". To put it otherwise, it was a valuable way to run less experiments for more values. For this purpose, he would explicitly make some claims, which are properly epistemological. He qualified the traditional way to proceed as "*linear*" since it would solely rely, to him, on "*extrapolations*" from partial results. Rather, he acknowledged the importance of "complex thinking", so to say, since what would matter to him were the interrelationships between the parameters, the complex patterns of interactions than a linear one-parameter-at-a-time would fail to capture. "*It can be mathematically proven that it's not the best way of doing it*".

Of course, for achieving this goal, he had to rely on the software. I asked him if the software could possibly miss the "*best combination*" (as he was striving to

find the "*best combination*" or the "*best fit*"). As a matter of fact, it would prescribe 46 experiments instead of 256. What if the best solution was to be found in the 210 skipped possibilities? He proved me wrong by faithfully relying on the software. The software does the job and relies on mathematical models. Plus, "*it also calculates the margins of error*". If it calculates the margins of errors, then of course it can't be wrong. It is important to remember here that this researcher was very conscious of the limitations of the traditional scientific methods and would endorse of a new way of apprehending multi-parameters models. Eventually, he could only either run less experiments or waste much more time or money. This way, he would expect to find the best parameters, which are of straightforward importance when it comes to the shaping of the chip. The outcome would either be a different thickness, width, angle or speed of insertion of the speed and, of course, to some extent, some more or less damages caused to a brain.

5.2.   *Picking up a neuron model: the pervasiveness to social*

In this case, one of the electrical engineers would run experiments about the first generations of probes developed by the team (rather than the still experimental 2nd generation), as his PhD committee suggested to him. In order to do so, he would use a method called Finite Element Modeling (or Finite Element Method – FEM). Insofar as I understood, FEM is a software-based, numerical technique that aims at finding approximate solutions to very complex sets of equations. For example, here, this researcher would try to predict whether a neuron would react or not to an electrical signal released by an electrode positioned on the chip, all this virtually (not in vivo in this first step). He would have to pick up a

complex system and to "mesh" it. Meshing is a representation of such a set of finite elements. Basically, meshing consists in dividing an object into distinct part so that each could be individually calculated, providing a simulation when these separate elements are reunited (in that sense, it is very close to Descarte's scientific method). The more the represented reality is divided, the more precise and accurate is the overall picture one get out of it, but also the more time it takes to simulate it (it takes a huge amount of computer calculation power – some simulations last for more than 24 hours). As I mentioned, in this case, the researcher would try to simulate the behavior of a neuron, so that he had to pick up a "neuron model". According to him, a neuron model is "*a representation of a real life neuron in a software as such. So, if I give a certain voltage value to the software, it tells me whether a real life neuron would be stimulated or not, based on knowing the physics of neuron*". In this case, I followed the whole process of picking up a particular neuron model (instead of plenty of other ones available). Three considerations shaped his eventual choice. First, the one he picked up was simple to use and would provide an accurate, yet rather basic and simple, picture of a neuron. Second, the model was designed at Yale University and would be widespread within the scientific community, widely acknowledged as a reliable model and used in many pieces of academic literature. Third, this model (which is software after all) is open-source, which means it was elaborated for and by an actively contributing community, carrying along manifold values endorsed by the scientific community about sharing knowledge, valuating collaboration and the like. Also, as most open-source software (but not all), this neuron model was free of charge.

What comes out of this case is the very deep **pervasiveness** of the "laboratory" to the outer social world. It is not a revolutionary statement, but still it is good to remember that laboratories or, in this case, R&D facilities don't work in insulation, rather all the opposite. Here, at least two elements point out to such pervasiveness. The first one is obviously that the choice of running simulations with the 1st generation probe was not a choice of the researcher himself, but rather a "recommendation" of his PhD committee, formulated at his mid-term defense. Well, the kind of advice I guess you want to take on. "*I wanted to investigate it but in a different way, not this way or so. But this way is a better option, it's more innovative… It's nice as such*". More notably however was the second clue of pervasiveness, where the reputation of Yale University as well as the actual use of the model by other scientific authors proved determinant criteria of this decision. Of course, once more, picking up this model or this one, a more sophisticated one or a more simple one, running more or less experiments depending on the time to allow for this, all this further influences the shape and actual power of the electrode placed on the chip.

5.3.   Releasing glutamines: real-time ethics

This third case is more basic. It is rather an illustration of what the chip could do in the future. Imec chip is expected to have great outcomes in terms of biomedical applications. With a better understanding of the neuronal cells and their interactions, one could expect to provide solutions or answers to degenerative diseases of the brain, such as Alzheimer's disease or Parkinson's disease. This noble goal was put up front by each and every researcher I met, even though most of them would step back from this goal. It would be a long-

term goal, many steps from now, a far-reaching target but not an immediate expected outcome. Besides, through interacting, I could find out many other potential outcomes than "*curing a degenerative disease thanks to a material chip*" (so to say – my paraphrase). In this third case, the researcher was playing around with different chemical compounds dissolved in a solution including neuronal cells. This researcher would stimulate this solution with an electrical signal, in order to find out which ones would provoke a reaction, in vitro. He would more specifically seek for glutamine release.

> *"Some diseases or disorders in the brain are results of improper communication between the neurons, so if you don't have enough of something, or, hum... If you have a defective transmission of neurotransmittors, then the next neuron maybe can't physically take it and, for the neuron that gives it, can't take it back. So, there are urges to find neurotransmittors there (...) That's why when you take drugs or something you're very happy or whatever because they increase the glutamine, hum, secretion in your brain. But then, when you get off drugs, then you feel sad. Why? Because your brain's back to a regular level. And a regular level isn't the happy level that you knew, or that you experienced, so that you feel sad, right? So that you take any more, to get even happier. So, hum... That would be some kind of... Yeah, I mean, these drugs are then over-secreting glutamine and over-stimulate the brain".*

> ***Interview 008 (2010-03-12), 26' 35.***

To make it simple, there is an obvious **ethical** issue here. First of all, whatever could come out of these experiments is not an intended outcome of imec's researcher. It could take the form of a new drug that either enhances communication among neuronal cells or help release glutamines. In any case, it wouldn't be something of an outcome that would have been scheduled and pursued as a goal from the scratch. A second element important to highlight is that such glutamine release deals with an alteration of personality. According to this researcher, one doesn't feel sad anymore but rather happy. We know from

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literature that a whole bunch of ethical issues are tied up with the development of brain implants and microchips: safety for the brain and the human body, issues of control over the brain, data protection, the stake of the informed consent of the patient [27], the whole problematic of human enhancement (what if a chip could help designing a "super-human"?), the question of potential military applications (dual use technologies) and, to finish with, the issue we are dealing with that is altered states of personality (see SCHERMER 2009 AND BERGER & AL., 2008). So, the course of research raises ethical issues that are directly linked to the actual capacities of the microchip, about whatever it is able to perform or to achieve which are proper ethical issues. That said, these ethical questions hold still when it comes to the unintended, side-effects outcomes of the innovation processes that take place at imec. Rather than the chip, they could be equally raised for a drug indirectly driven from the research provided on the chip.

5.4. Completing a successful PhD: when individual strategies shape science directions

The fourth and last illustration is more general as it deals with the whole PhD of the last researcher I engaged with. He would not work on neuronal cells as most of his fellow colleagues of the team, but rather on olfactory cells. These cells come straightly from the nose. By learning how to reproduce such cells and having them reacting to different signals, applications could be numerous, especially in the field of biosensors (cells that could "smell", seek and/or identify a broad array of potential elements). The point is that the PhD intended to follow

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[27] The patient is by hypothesis victim of a degenerative disease, so how does one make sure to have his proper informed consent?

this path: first, learn how to grow this kind of specific cells. Second, third and fourth steps, provide further experiments and eventually try to get something out of those. It so happened that the researcher proved unable to actually grow that particular kind of cells, since it is very unusual to specifically work on these (and very innovative thus). The result is that this researcher would have to struggle hard to make his way through his PhD and had to develop manifold strategies to get himself out of this predicament. He would be rather alone to deal with these recalcitrant cells, since other members of the team would mainly deal with neuronal cells rather than olfactory cells. He would order genetically modified cells from an external laboratory to provide different kind of experiments. He would try to engage with (one or two) specialized laboratories that proved successful in growing such cells, trying to learn from them but lacking means of trade-off (nothing to offer in exchange of this know-how). Whatever. The whole point there was to make something consistent and valuable out of the PhD.

The issue here is much more about **strategies**. Here, I witnessed individual strategies of reconfiguring an initial PhDs project. This had quite a lot of consequences on the material outcomes of the research provided as well as on the particular interactions I had with this researcher. As he would get involved into three or so different strategies without being successful up the point when I left, he would have relied on basically anything he could value or "sell" to his PhD committee. For example, he would test all different kind of configurations for his research culture. For each of these, he would perform about 20 experiments (which is a way to ensure a specific configuration *do not* work, so that you know

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for sure it is a way to avoid). He clearly told me that whenever one experiment was successful, he would not hesitate to build his whole PhD on this single successful attempts among potentially hundred of failed ones. By the way, it was something one could find in the literature on olfactory cells, pointing out to how poorly representatives were the successful experiments. For this reason, this researcher was the most willing to engage and interact with me, up to the point of coming to grab me in order to have a conversation (while the others would mostly passively wait for it). One may think of it as a "therapeutic feature" of engagement, as this person would find some relief in sharing his PhD issues with someone. There is another way to look at this: this person was more open to alternatives, was seeking solutions, would have welcome any useful advice on the directions to follow, lacking of both internal an external support.

In terms of material outcomes, there are two lessons to be learned. The first one is that whatever this researcher may have produced, it would probably not be an accurate representation of all the work provided. As most of researchers work with "trial and error" procedures, this one would unfortunately experience the bitterness of an "error and error" procedure, so that he could potentially rely upon any sort of even slightly successful "trial" with that particular kind of cells. The second lesson is that this researcher was somehow disconnected from the rest of the team's dynamics. While all the other would rather work on neuronal cells and seeking to improve the imec chip, this one would more likely run "fundamental" experiments on olfactory cells.

5.5.   Conclusions in terms of interpretive flexibility

As a short conclusion, each of the researchers I engaged with made research choices that really have material consequences on the shape of chip, the functions it would perform, its unintended side effects and the like. Therefore, there *is* a broad multiplicity of choices to be made – what one could call "interpretive flexibility" of the imec chip and the side effects of its development (such as new drugs). Each of these choices would be rooted in manifold considerations, in terms of what to expect out of experiments (and out of the chip), how much resources it would take, the accuracy of a particular procedure or, say, many other criteria that don't belong to scientific repertoires at all, like reputation or validation by the scientific community. All the three first case share the same goal, which consists in improving the chip, resulting in very material outcomes. The combination of all these experiments will lead in the future to the actual shaping of the chip as it will probably be mass produced, released on the market and spread over society. Interestingly enough, I found one of the researchers somehow "excluded" from this dynamics, precisely because his work would strictly relate to this chip but would so to say follow sideways. As I mentioned in the first part of this thesis, this was one of the powerful structural dynamics at play at imec. I shall expand a little bit on these dynamics as I found them incredibly shaping and constraining individual choices.

6. On structures: a twofold shaping of individual practices

I will only pick up two examples of how the work being provided by the different researchers within the "cellular interfacing" team is shaped by the pressing need to deliver actual prototypes. In a second time, I will show how the team itself was

dealing with overall imec strategies and programs, in order to make his way through. All this shows the powerful effects of structures over individuals, through a complex set of articulations.

6.1. The shared centrality of the microchip

The chip is at the core of the "cellular interfacing team" business. If one happens to analyze deeply the discourses I recorded with appropriate discourse analysis methods, one would probably find something puzzling about imec researchers. In most cases, scientists make a lot of claims about their work in terms of advancing knowledge, providing benefits to the scientific community, and yet develop artifacts, products to sell, seek funding, and the like. This twofold discourse, antagonistic to some extend, was salient in most similar case studies from different fellow PhD students from all over the world [28]. Still, I wouldn't find this kind of discourses playing around the cellular interfacing team's researchers. Rather, they would insist on the need to improve the prototype and on the (modest) contribution of their respective works for achieving this goal. In a way, as a material artifact, the chip would somehow provide the mortar that binds together the multiple perspectives, interests, strategies, scope and disciplinary backgrounds of all these researchers. I argue it would play this role just as a scientific instrument can generate unity among the different members of a research team (THOREAU & NEICU, 2010; SIMOULIN, 2007). To put it otherwise, the chip could be the material equivalent, *ceteris paribus*, of the "shared cognitive frame" theorized by Bijker (BIJKER, 1995).

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[28] These results were presented during a workshop held in Vatnahalsen, NO, August 2009.

As a research manager, Wolfgang is mainly interested in developing working prototypes. In the team dynamics I mentioned in first place, it was fairly salient that the whole work provided by the team was directed toward industrial partners that would provide financial means (and therefore further research opportunities) in return. In this respect, the centrality of the microchip was even reinforced or at least constantly underlined. All researchers would keep on working bearing in mind the actual importance of providing, or helping to provide, an actual material prototype as an end-goal of all this process. This would have very strong consequences in terms of framing each other's work, strategic goals or even research interests. All of this was strongly directed toward the development of the chip. I found a very nice piece of evidence of this, as Wolfgang was busy constructing a roadmap leading to prototypes, in the first months of his new managerial position. I couldn't picture this one (as pictures were forbidden for intellectual property reasons), but it would look like this picture.
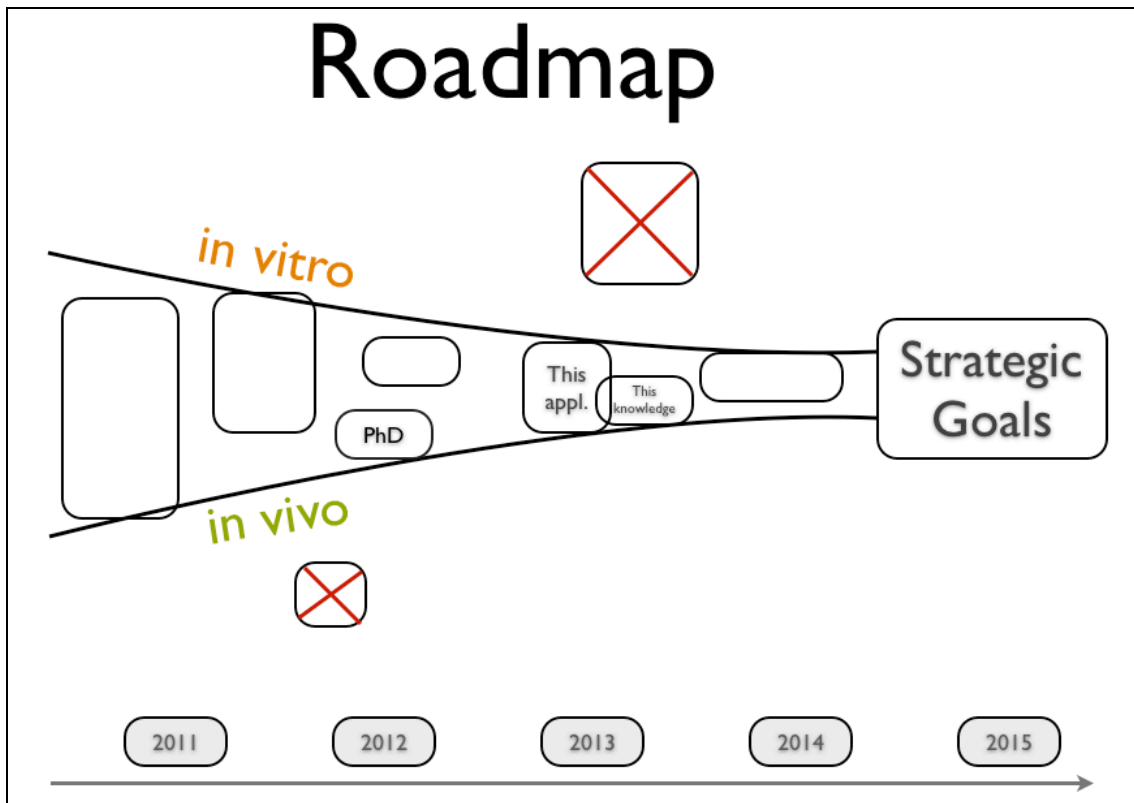
Fig. 3: representation (more or less accurate) of the "cellular interfacing team" roadmap.

This roadmap was co-constructed together by Wolfgang, a "strategy" sub-group created among team members *and* industrial partners. Wolfgang orchestrated the whole process and of course provided inputs as for the roadmap. He involved any interested senior researcher to contribute: some took on this challenge; some other didn't, depending on their interest in these issues. He also and mostly involved industrial partners that would provide him with manifold advices in terms of which directions to follow, in which timeframe, with this calculation power rather than this one, avoiding to go this direction because this or that competitor was already closer to reaching this goal, but instead going into this or that direction up to date under-invested, etc.

This of course has very strong constraining effects on the team's work. First, it is

made out of building blocks (each cases on the fig. 3). Each of these relate to a particular accomplishment, a PhD that is needed, a goal to reach, and the like, in order to provide a working prototype by the end of the process. Second, it intends at merging in vivo and in vitro dynamics, which would make this merging mandatory rather than simply "desirable". Lastly, it would only allow participation insofar as it would fit the roadmap as a framework. For instance, on fig. 3, red crosses point out to research directions that, although interesting, wouldn't fit the roadmap framework and therefore would be excluded in the future. It could take the form of PhD proposal, even though funded by the University, which could get rejected by the cellular interfacing team, as it doesn't fit the strategic goals.

6.2. The team within imec : roadmapping the future, constraining individuals

This evolution toward a rather strict roadmap strategy would of course take place in the broader context of imec as a whole, as an entity competing in an increasingly competitive global landscape. As a R&D center, Imec relies more and more on funding from private partners. Public funding, while constant on a absolute basis, kept on decreasing over years on a relative basis, transiting from 100 % to a mere 15 % in 2010 (as private funding would constantly increase). As I mentioned at the beginning of this part, imec develops itself around three central programs. Surprisingly enough, the cellular interfacing team was not really involved in any of these. The exercise of the roadmap would take place in a broader strategy to catch up with imec dynamics and leading programs. In order

to understand further structural constraints that lies on the team and therefore of the work of every and each of his members, it is enlightening to look at the role of imec in society as Wolfgang understands it [29].
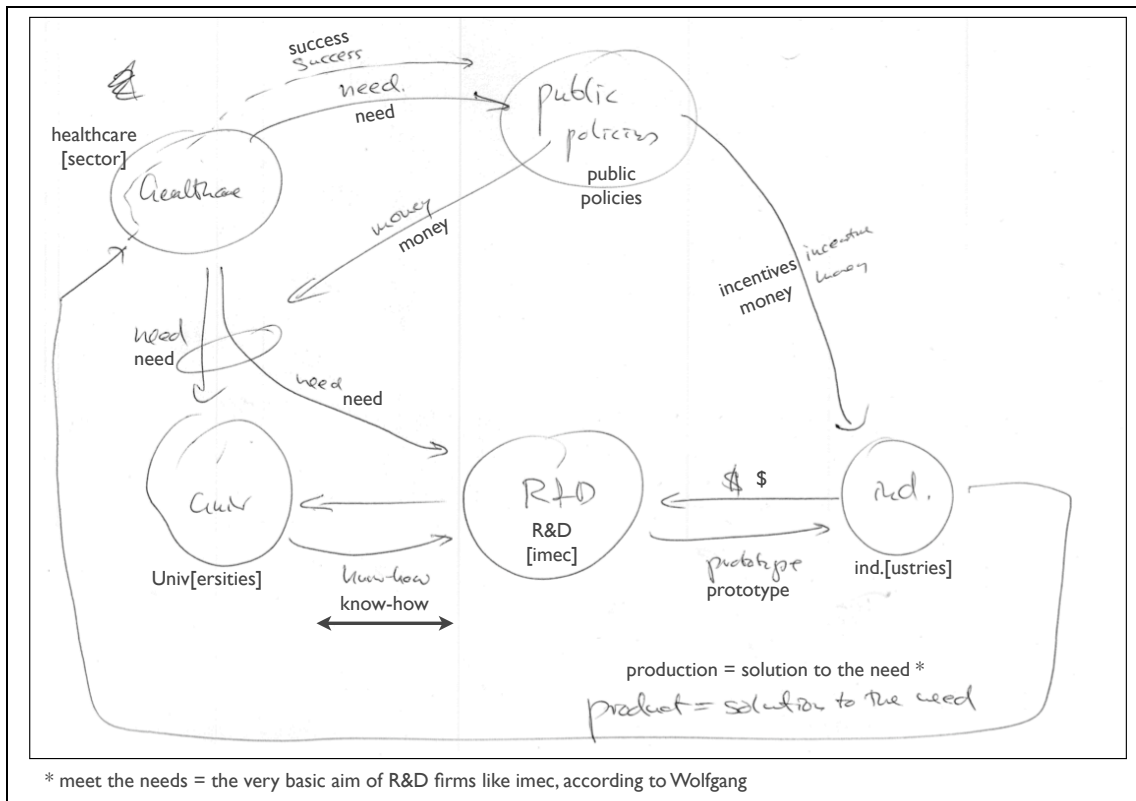
Fig. 4: relationships of imec (R&D) and different societal actors / sectors.

I do not have the proper space left to elaborate on this picture as much as it deserves. Still, one may observe three different elements. First, imec only delivers products, and do so in order to provide "solution to the need". Clearly enough, imec has its own interpretation of what societal needs are and attempts at fulfilling them. This of course happens at the highest levels of strategy but, as this picture suggests, it would impact all their innovation chain up to rather small teams as the cellular interfacing one. Second, it more and more escapes to

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[29] I shall mention that I do think that Wolfgang has a really strong uptake on strategic matters, and that therefore I consider this picture as rather accurate in terms of standing for imec's visions of its development.

political control. Imec is considered to be a huge success in terms of innovation policies. But, as the public/private dynamics of funding illustrate, it has the paradoxical effect to drive imec away from political authorities – which is precisely the main criterion for assessing success. This state of affairs is found on this picture, in terms of the weak control of political authorities. According to Wolfgang, such political orientations to the innovation process would only occur through incentives, themselves driven from the needs of the healthcare sector, and would need to be processed through industries before imec could perceive them. Of course, this picture is certainly not complete. Still, it tells us something about the increasing autonomy of imec as an innovation actor. Third and last element, imec would have only two direct relationships. One with industrial partners that would provide some money in exchange of prototypes they could sell. Interestingly enough, it happens more and more that industrial partners eventually hold the patent and delocalize the production of end-user products to Asia, turning imec into a mere service center. But it's not the point here. The other direct relationship is with Universities (especially KUL), but only insofar as these could provide imec with know-how.

Wolfgang constructed his roadmap keeping in mind this vision, all the time. He knew exactly which actors he would need to rely on and for which purpose. It goes without saying that the fig. 3 and 4 would deserve a thesis by themselves, as they could be unpacked again and again, raising manifold important issues. Still, I couldn't skip these elements neither, as they would point out to the powerful structural constraints that translate the global competition landscape into imec policies and strategic pillars of development, that are themselves translated into

Wolfgang's roadmap and that eventually will have the very strong effect of preventing someone from doing his University-funded PhD in the cellular interfacing team, or will orient the research directions of other researchers hired by imec for the next few years. So, these structural effects are obviously out there in my case study.

Conclusion

In this thesis, I provided a particular theoretical understanding of the notion of "interpretive flexibility", as it was developed by the EPOR and then by the SCOT approaches. I adapted it to a particular framework that would fit most accurately the case of nanotechnologies. I struggled hard to make this point, as I had to take many detours in order to show how it matters to problematize and contextualize "nanotechnologies" and, eventually, all that a SCOT approach could bring in terms of understanding their development(s). I showed the paradoxical dimensions of public action regarding nanotechnologies as well as their contrasted history. I addressed and questioned their "profile of technoscience". I ended up making a plea for the irreducible heterogeneity of nanotechnologies and the importance to focus on empirical issues, and the importance to engage with actual ongoing developments henceforth. All this introduced me into a large-scale R&D center where I observed the "interpretive flexibility" of (nano)-technological artifacts in-the-making.

I found out manifold variations that allow for flexibility and that could potentially integrate much more elements than what they actually do so far. For

instance, issues such as competing epistemologies, deep pervasiveness of research methods to social considerations, playing around with ethics or struggling one way through his PhD, were constantly popping up. From these examples, we learned that the concept of "interpretive flexibility" not only fits social groups, as in Pinch & Bijker's approach, but also micro-practices of researchers, shaping further the design of technological artifacts. However, this refreshed understanding of the interpretive flexibility of outcomes of the innovation process should not lead to straightforward conclusion. It takes a greater consideration to the powerful structures at play, which thoroughly shape and constraint individual's role, while being very slightly shaping by them in return. These contextual dynamics do exert an overwhelming force on researchers that recalls the lively tenets of technological determinism. Of course, this does not suffice to shut down decades of constructivist perspectives, and one must find his way through these dynamics and make sense out of what happens at a micro-level. Otherwise, it would just be a matter of resignation.

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