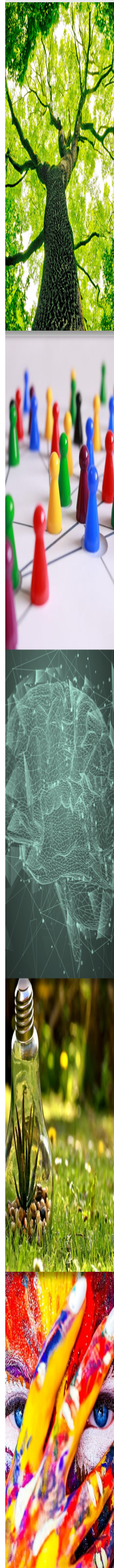
Théorie et Méthodes de la Conception Innovante

Principales publications 2020



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Innovation Theory and the (Re-)foundation of Management: Facing the Unknown

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Setting the stage for this special issue

Within the management research community, the last few years have revealed a growing desire to focus explicitly on new discoveries and to challenge the very foundations of our discipline. This special issue addresses how innovation-management theories might enrich management science, helping to discover new phenomena and formulate research hypotheses with relevance for the entire discipline.

Contemporary managers face many challenges when shaping new industrial ecosystems, engaging with disruptive technologies, inventing new business models, or even re-inventing their own organizations. An interesting recurring theme in all these contexts is that they involve not just uncertainty, but facing the unknown. While uncertainty refers to events that are known, and whose probability of occurrence can be estimated (as inherited from statistical decision theory), the unknown denotes events that can be expressed conceptually, but can hardly be imagined, and therefore cannot be described. For example, tomorrow's weather is uncertain, but forms of extraterrestrial life are unknown. While uncertainty can be reduced (e.g., by statistical sampling), the unknown must be explored through an effort of imagination.

In innovation management, the way innovators relate to the future is closer to exploring the unknown. They don't regard the future as 'uncertain,' but as a matter that has to be shaped, transformed, named, and generally invented in a proactive way. This perspective could also be useful to general management.

Some innovation management concepts have already enriched mainstream management literature. 'Organizational ambidexterity' (Duncan, 1976; Tushman and O'Reilly III, 1996; Gibson and Birkinshaw, 2004; Tushman et al., 2010), which was initially proposed as a way of organizing for innovation, has more recently been acknowledged as a fundamental notion in organization studies (Birkinshaw and Gupta, 2013). The concept of 'absorptive capacity' has enjoyed a similar crossover. But despite these individual examples, innovation management has largely remained a 'specialization,' as illustrated by journal rankings in many countries, preventing it from taking root in management science. The purpose of this special issue is to bring insights from innovation management to the very heart our discipline.

Note: This is a co-authored editorial; authors appear in alphabetical order.

We now summarize the six papers included, before discussing how they contribute to (re-)visiting and (re-) founding management science with innovation theory. These six contributions link innovation management and management foundations.

In 'Understanding the invention phase of management innovation: a design theory perspective,' Albert David examines the invention process of a single famous management innovation: Drucker's 'management by objectives' (MBO) concept.

In 'A century old and still visionary: Fayol's innovative theory of management,' Armand Hatchuel and Blanche Segrestin revisit Fayol's legacy and argue that, contrary to previous analysis, Fayol positioned innovation at the very core of management science.

In 'Contracting for the unknown and the logic of innovation,' Anna Grandori and Marco Furlotti identify specific types of contracts for managing innovation, which they term 'constitutional contracts.'

In 'The design logic of new business models: unveiling cognitive foundations of managerial reasoning,' Dirk Schneckenberg and Vivek Velamuri uncover the cognitive processes used in creating innovative business models.

In 'Experimenting in the unknown: Lessons from the Manhattan Project,' Sylvain Lenfle and Thomas Gillier show that Thomke's model of experimentation was actually built for experimentation in uncertainty, and extend it to the unknown.

Finally, in 'Designing decisions in the unknown: towards a generative decision model for management science,' Pascal Le Masson, Armand Hatchuel, Mario Le Glatin, and Benoit Weil address the issue of designing decisions in the unknown.

(Re-)visiting and (re-)founding management science with innovation management

It is a privilege to be able to include, in just one issue, papers addressing the work of groundbreaking founders of management science such as Fayol (Hatchuel and Segrestin), Wald (Le Masson et al.), Drucker (David), and Simon (Grandori and Furlotti. These papers will encourage our readers to reengage with the legacy that these great authors left to management science. The papers also provide a panorama of the management science discipline, from its historical roots (Fayol) to the most recent trends (business-model innovation), while revisiting key inflection points (e.g., Drucker). Last but not least, the papers adopt a trans-disciplinary perspective: even as they work towards the (re-)foundation of management science, they articulate its position in relation to other disciplines such as economics and sociology (Hatchuel and Segrestin); re-examine its roots in statistics (Le Masson et al.; Lenfle and Gillier); and make use of cognitive science approaches (Schneckenberg and Velamuri; Le Masson et al.), legal concepts (Grandori and Furlotti), and design theory (David; Grandori and Furlotti; Le Masson et al.).

Beyond this rich panorama, there are three ways in which the six papers, taken together, contribute to the (re-)foundation of management science using specific concepts from innovation management.

Revisiting the classics

First, the papers exhort us to revisit some classic notions of the management discipline. It is inspiring to see how each paper, taking the perspective of innovation management, uncovers new limitations of established theories and pushes research to go beyond the 'common sense' of management. David discusses 'management by objectives,' often taken to be a self-evident notion. Hatchuel and Segrestin revisit Fayol's administrative theory, which is usually seen as the application of scientific rationality to administration. Grandori and Furlotti revisit a commonly admitted assumption—namely, that contracting in the unknown necessarily leads to an 'incomplete contract.' Schneckenberg and Velamuri explain that business models can no longer be considered a reference frame for how to meaningfully interpret information in contexts that include high levels of both complexity and novelty. Lenfle and Gillier revisit the notion of experimentation, which is usually considered a good way to reduce uncertainty. Finally, Le Masson et al. show that decision-making is not the only way to behave rationally. In so doing, they re-examine not only rational decision-making, but also its inherent dark side: the assumption that creativity is necessarily irrational.

New methods inspired by innovation-management research

A second contribution is that the papers propose a set of new methods, stemming from innovation management, to extend the classics. David and Le Masson et al. apply design theory to management classics: the invention of managerial notions (David) and the decision (Le Masson et al.). Meanwhile, the papers by David and Hatchuel and Segrestin rely on historical method and a genealogical approach to understand the evolution and dynamics of meanings.

New notions to extend the classics and (re-)found management science

The third contribution may be the most important: by revisiting the classics, the papers don't just raise criticisms—they also propose new notions to extend classic ones.

For instance, David analyzes the unknown in management techniques—the paper shows how the design perspective uncovers the internal coherence of a managerial technique, beyond its multiple facets such as process, practice, instrument, organization principle, mindset, and performance logic. The author considers management as a design process and management innovations as the managerial artifacts that result from such design effort.

After discussing the limitations of contracts, which imply known outcomes and clear problems to be solved, Grandori and Furlotti propose a new notion: 'Constitutional contracting'. This is adapted for facing 'the unknown,' and situations where 'means are in search of uses.' This new contractual type is procedural rather than substantive, constitutional rather than operational, and democratic rather than hierarchical.

Gillier and Lenfle propose new principles to extend the logic of experimentation in the unknown, based on the capacities to identify the unknown (not just the uncertain), to design new descriptors (and the formal models and theories attached to them), and to design the instruments to characterize these new descriptors.

Le Masson et al. propose a formal model to systematically map the design paths leading to the design of new decision options. The authors show that contemporary design theory can help us plot a systematic, rational path to design decisions in the unknown.

Finally, Hatchuel and Segrestin, revisiting Fayol's legacy, reveal that, for Fayol, management science is inseparable from innovation. Following Fayol, who put the logic of innovation at the heart of managerial action, management is necessarily a theory of creative/political rationality where collective action is structured by coping with the unknown. This suggests that management should be the science of 'creative, scientific, economics and social advancements.'

Management science as a science of the design of collective action

Of course, these six papers are but a small sample of all the efforts to link innovation theory and management science. Nonetheless, they invite us to develop this collective endeavor more systematically. They also remind us that modern management was created by innovators such as Taylor, Fayol, and Parker Follett (O'Connor, 2000)—famous founders who did not just conceptualize and characterize new forms of collective actions, but even invented them. These works remind us that innovation was historically at the heart of management science—and that without innovation, management science would be locked into a spiral of imitation and reproduction.

Moreover, the work in this issue illustrates that innovation management today pushes us to revise and challenge the basic notions of management science. Previous discussions in management science have elaborated theory by building polarities, often corresponding to 'theory' vs. 'practice' or 'optimal rationality' vs. collective heuristics and biases. But managing in the unknown obliges us to go beyond such polarities. We need a new rationality: the design of new forms of collective action. These six papers help unfold this new paradigm of management science.

If management is about designing collective action, management science can be considered the science of inventing new organizational logics, new rationality, and new values. It is management science that discovers these things; conceptualizes them; perhaps even proposes them and helps experiment with them. This new paradigm is coherent with the essence of management science (see Hatchuel, 2005), which is neither a fixed repertoire of forms (and hence different from an 'applied sociology') nor the direct consequence of rational optimization (and hence different from an 'applied economics'). This new paradigm of management science also has a promising future, because it constitutes a 'post-decisional' paradigm—one adapted to contemporary unknowns and the invention of new societies, new industries, new skills, new knowledge, and new dreams of the future.

We hope you will enjoy these six papers as much as we do, and that your insights and inspiration will repay the efforts of all the authors, reviewers, and editors who have worked so hard to produce this special issue. We owe them all a great debt of gratitude.

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INNOVATIVE DESIGN WITHIN TRADITION - INJECTING TOPOS STRUCTURES IN C-K THEORY TO MODEL CULINARY CREATION HERITAGE

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ABSTRACT

In "Grande cuisine" creation and tradition co-evolve in a rich number of ways. Great chefs still use recipes from the 19th century and may also reinvent gastronomy itself. The creation heritage of culinary Art is the paradoxical capacity to both "respect" tradition and "break" its rules. Building on C-K theory, we show that such creative heritage needs multiple and independent layers of knowledge that "speak" of basic fixed objects. These properties correspond to general mathematical structures that we find in Topos theory. Thus, C-K/Topos predicts creative design strategies that can respect tradition in different ways. It also proves a form of "innovation within tradition" - "sheafification" in Topos words- that is not a compromise and builds on tradition itself. These findings fit with the lessons of great books of gastronomy. C-K/Topos has a wide scope of validity: it applies to any innovative design that needs preserving systemic structures, like engineering systems or social and environmental systems. C-K/Topos models with a high generality how local and radical innovation can warrant systems incremental change. C-K/Topos will have implications for teaching and research.

Keywords: Creation heritage, Tradition, Innovation, Design theory, Knowledge management

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INTUITIVE MOTIVATION: THE CREATION HERITAGE OF CULINARY ART?

What is the heritage of a creative craft? "Grande cuisine" is one of the most iconic crafts where creation and tradition *co-evolve* in a rich number of ways. Great chefs still use common food ingredients and classical recipes already described in Cuisine books of the 19th century. Other chefs have *reinvented* meals, culinary techniques and redefined gastronomy (Agogué and Hatchuel 2016) or use design methodologies to foster creativity (Capdevila *et al*., 2015) while . Actually, culinary Art have long been the subject of important transmission efforts. They gave rise to famous "grande cuisine" treatises that had a major impact on the creative development of the craft. Intuitively, we are facing a paradoxical notion: the *heritage of culinary Art* appears as a "creation heritage" which is a capacity to both: i) "*respect*" a craft tradition; and ii) "*break*" traditional rules and regenerate the tradition! Most natural view is rather that tradition and innovation are contradictory or that a creation heritage only teaches designs compromises between tradition and innovation. It is more difficult to think that tradition could guide and foster innovation. Therefore, Culinary art challenges our views about tradition and innovation. It also offers a good empirical reference for studying the enigma of a "creation heritage": what type of knowledge can contain both fixed rules to be respected and a creative potential? *The purpose of this research is to establish a formal description of the structure, logic and conditions of a creation heritage.* In this paper we explore, with the perspective of C-K theory, how such creative heritage can correspond to special mathematical structures that help modelling the "respect" of tradition in a richer way; and reveal forms of innovation that have their source in tradition itself. Our research assumes that the culinary creation heritage has been encapsulated in influential books that have been landmarks in the history of gastronomy. However, beyond culinary art, the model developed in this paper has a much larger scope of validity that we highlight in our conclusion.

Research methodology: modelling a creation heritage with C-K theory. To elaborate a general model that captures a creation heritage and its forms of creative design, we have followed different steps that are developed in the sections of this paper.
a) We build on C-K theory as a universal model for creative design (Hatchuel and Weil 2003; Hatchuel and Weil 2009). C-K theory defines a family of models **C-K/X** where **X** is a specific knowledge space. The structure of X, determines a corresponding creative capacity or design regime (Le Masson *et al*., 2017). Hence, our research question becomes*: what are the structures of X such that C-K/X describes a creation heritage that also respects tradition?*
b) From analysis and the study of culinary books, we first establish that a creative heritage including tradition follows *a canonical model* of the form **C-K/Knh(Kn-1h(…(K1h)))** where Kih are layers of knowledge such that : i) no layer Kih determines another one; and ii) Traditional objects common to all Kih remain unchanged by design. Thus, our new question: *is there a good mathematical interpretation of such canonical model and what can it tell us about CH?*
c) We found that the mathematical structures of a Topos mirror the canonical model of CH. Topos theory studies with a high generality, *universes of objects and relations* that require several *levels of description*: for instance : i) different logics built on the same geometric space ; or ii) global and local properties of a universe. In this section, we give an elementary introduction to Topos notions and we show that C-K/Topos captures all paradoxical aspects of a creation heritage and reveals how tradition can be respected and still guide creative design strategies. Topos allows modelling "innovation within tradition" in a rigorous and general way.

1 PART 1: A CREATION HERITAGE: LAYERS OF KNOWLEDGE, GENERATIVITY AND TRADITION

1.1 Beyond know-how: A creation heritage as a generative heritage

The first component of a creation heritage CH is a list *of know-how propositions K1h* easily taught to a person. In Gastronomy, it is usually a description of cooking recipes. However, we know from C-K theory (Hatchuel et al., 2018; Hatchuel et al., 2013b; Hatchuel et al., 2011a) that new designs are

possible only if K1h verifies universal conditions for generativity (UG conditions)[1]. Obviously, a pure list of cooking recipes or a "lego type" recipes - common to cooking books - do not fulfil UG conditions and **C-K/K1h** is not a creation heritage.
Consequently, a creation heritage needs another layer of knowledge K2h that fulfils UG conditions. Moreover, K2h cannot be deduced from K1h otherwise K2h would be part of K1h. Conversely, K1h cannot be deduced from K2h: if this was true, K2h would be itself a know-how that does not fulfil UG conditions. Thus the creation heritage is at least of the form **C-K/K2h(K1h)**. the symbol K2h(K1h) means a structure of knowledge where the layer K2h "speaks about" objects of K1h without constituting a proposition of K1h.
Example: culinary books foster generativity, for instance, by associating new qualities to a meal without giving the new recipe. In El Bullis's manifesto "Synthesis of elBulli cuisine" (see appendix), the great chef Ferran Adria states that "*Cooking is a language through which all the following properties may be expressed: harmony, creativity, happiness, beauty, poetry, complexity, magic, humour, provocation and culture*". Thus any classic recipes, menus, dressings, aesthetics of the tradition can be revisited and new concepts generated like " a provocative tortilla". But CH must also include the respect of tradition.

1.2 Tradition heritage as a regulatory knowledge

A creation heritage needs also to define the content of tradition[2]. One role of tradition is to *limit the capacity to change existing know-how*. Hence, the creation heritage includes a third level of knowledge **K3h** that controls if some creative design respects the craft tradition. **K3h** is a regulatory knowledge that "tunes" the generative power of C-K/ K2h(K1h). Hence *the existence of a craft tradition implies that a creation heritage is of the form* **C-K/K3h(K2h(K1h)))**. K3h can be also a generator of design strategies that helps balancing between tradition and innovation in different ways. In the domain of Culinary art, we can observe design strategies where tradition is maintained partially. For example, redesigning a classic French recipe (tradition) with the purpose of adding freshness {Hatchuel, 2009 #1549} or fatless diet.

1.3 Canonical model of a creation heritage: Generativity, independences and respect of tradition

The series K1h, K2h, K3h is a special case of a more general logic. The balance between tradition and innovation can be itself regulated by another level of knowledge **K4h** that changes that balance by associating new references (Art, fashion..) or new cooking cultures (European, asian, African..). For the sake of generality, we need assuming a variable number if of knowledge layers: **K1h, K2h,.., Knh...** Then the canonical form of a creation heritage can be finally defined as: **CH = C-K/ (Knh(Kn-1h(Kn-2h)…(K1h)))))** if the following general properties of the Kihs are assumed:

- **Generativity**: At least one layer Kih fulfils the UG conditions
- **Independences**: no layer can be deduced from any other: this means that each layer brings independent information.
- **respect of tradition**: All layers of knowledge can evolve, yet there exists a basic structure of objects and rules that is common to all layers and will serve to define what means "respecting" tradition.

Examples. Great culinary books offer numerous illustrations of such canonical model. As predicted, they all are organized in independent different layers of knowledge. For example, in famous books (Dubois and Bernard 1856; Escoffier 1902), funds and sauces are both considered as the core of the art

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[1] Generativity conditions are: expandability, existence of concepts ("holes of undecidability"), splitting condition (Le Masson et al. 2016) allowing new designs from concepts (Hatchuel et al. 2011a; Hatchuel et al. 2013a)
[2] If complete freedom of design exists there is no tradition to be respected. This situation corresponds to highly innovative domains i.e. when *creative design* can lead to complete changes *in the identity of the techniques and objects of the domain* (Le Masson et al. 2016). Examples exist in engineering (mechanical engines can be replaced by electric ones; analogic music can be replaced by digital sounds, robots can replace drivers…). Contemporary forms of Art are also good examples of free creation heritage.

and also a space for new designs. Funds and sauces are not complete meals recipes. They form a special layer of knowledge and the use of sauce in recipes is both traditional for some meals but a same sauce can be associated to a large variety of recipes and meals. The same logic appears with « croquettes » which can « have infinitely different forms and compositions » (Dubois and Bernard 1856). Above recipes, funds and sauces, another layer of knowledge informs about « well composed menus » (series of different meals) which should be adapted to circumstances and clients. They have to express « a sure design, a high talent, and well balanced spirit that masters all the resources of culinary art » (Dubois and Bernard 1856). Ornaments introduce another layer of knowledge. For a good ornament Escoffier indicates that : "to reach this result, the inventive worker has numerous available means: using only edible elements like truffles, mushrooms, egg whites, vegetables, tongue, etc. , she can combine an infinite variety of admirable ornaments". In this case, Escoffier fixes the tradition "ornaments should be edible" and opens for generative design.

As indicated above, all these levels of knowledge clearly do not determine each other and do not lead to a unique set of cooking recipes. Menu are composed of meals, but the composition of meals is not fully determined by the menu. Ornaments depend of the meals but also of the context of the menu. Thus the canonical model of a creation heritage is clearly not a fixed set of fabrication and assembly rules. Each layer of knowledge introduces new objects and new relations. Each one organizes a specific perspective about the universe of recipes, with its own share of tradition and space for free creation. All these levels of knowledge are also interrelated; and they all, in their own way, « speak » of the same basic objects. They form a creation heritage and confirm the canonical model introduced before.

However, this canonical model raises several technical questions. What allows tradition and creative design to co-evolve without creating contradictions or destroying the craft's unity? In this process, is innovation just "constrained" or is there a new form of innovation that is related to a creation heritage? To explore and answer rigorously these questions, we need a formalized representation. Thus, our research question can be now expressed more technically: can we find a mathematical model that mirrors such multilayer structure and its three specific properties (generativity, independence, and tradition)? If such model exists, what does it tell us about innovative design within such structures?

2 PART 2. C-K THEORY AND TOPOS THEORY: MODELLING INNOVATION WITHIN TRADITION

There is a long history of knowledge representation. The first tradition developed after Herbert Simon described knowledge *as sets of rules*. Later, knowledge was described with ontologies or Type models. In mathematics, the last decades assessed the generality, richness and power of Topos theory which introduces very flexible representations of knowledge that can cope with global and local structures of knowledge. Topos also can combine in a unique and general way both space properties and logics. Topos appeared as the best candidate to formalize the canonical model of CH and its properties for the following reasons:

1. *Topos can be built on one fixed category*
2. *Topos capture universes that present layers of information and are too complex to be described by Sets and standard logic* (Prouté 2007))
3. *Topos have a generative power*. It was shown that the technique of 'forcing' (Cohen 1963) ie. a design of new models, can be generalized in Topos theory (Tierney 1972). Hence C-K/Topos fulfills the UG conditions.

Now we establish the close correspondence between C-K/ Topos and a creation heritage. In this section we give elementary notions about Topos theory focusing on those which are relevant to the formalization of a creation heritage. In the following, we describe *the interpretations that we associate to the building category* **C**, *presheafs* **PSh**, *subobject classifiers* **Ω**, *Sites* **S**, *and Sheafs* **Sh**.

2.1 The building category C and its presheafs

The building Category C represents a first layer of knowledge about objects and relations of the Topos. It corresponds to the *basic knowledge that defines the tradition of the craft*. For Culinary art, C describes the main definitions of ingredients, meals, menus, recipes, techniques and habits that compose the common knowledge of the Craft. For modern cuisine the famous Escoffier Book is a good inventory of that knowledge. It can be seen as the *Know-how K1h* that any chef should know, even the most innovative ones like Ferran Adria (El bulli's manifesto).

A Topos is not limited to C but contains all applications F(C), called *presheaves on C* (Psh (C)) from C to any set of values. For instance, the Topos contains presheaves describing the "nutritional impact" of objects in C. or their "gastronomic values". Metaphorically, the category C plays the role of a basic "geometry" or "space" in which one 'describes' some new aspects than C itself. To one unique category C will correspond many presheaves, i.e. many layers of knowledge which share a reference to C: they "speak" about C . The structure of a Topos can be represented by the figure below (Kostecki 2011)).

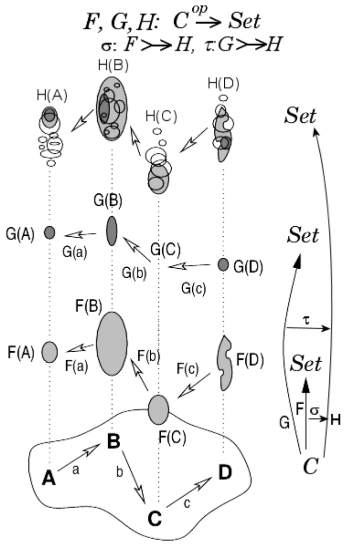

Figure 1. (taken from (Kostecki 2011)): A category of pressheaves. The category C has the objects A, B, C and D and the arrows a, b, c (and the compositions); F, G and H are presheaves of sets on C.

Proposition. *If presheafs are independent, a Topos has naturally the multilayer structure of the canonical model of CH.*

2.2 Subobject classifier of a Topos: Modelling the laws of tradition

Moreover, in Topos structures, the consistency of tradition is warranted by the stability of C and by its internal logic. This logic is precisely described by a central notion of any Topos: the subobject classifier that we introduce by an example.

Let us assume that a chef has to select the dishes that are adapted to "a luxury dinner", he will build a presheaf on C (an application of C on some Kih) - that we call "Lux" - which is also a subobject of the Culinary Topos. To be consistent with C, the entities of Lux have to be "dishes": i.e. they must respect the structure of dishes in C. Assume that in C, all dishes are composed of a meat and sauce and a meat never goes without sauce. Hence, Lux is necessarily composed of only three classes of objects: *Dishes that are in Lux with meat and sauce, Dishes that are not in Lux, Dishes that are in Lux but only with sauce (a sauce that makes lux in itself)* . Note that the classic set theory answer would be "dishes that are, or are not in Lux". The structure of C, the cooking tradition, appears in the existence of the third possibility: *dishes that are in Lux but only with sauce.* Let's underline that this richer logic of the topos comes from the interdependence between objects fixed in C. Moreover, it is a theorem of Topos theory, that :

- the composition {sauce → meat → dish} will *impact all presheafs in the Topos* i.e. all subobjects of the Topos and
- this impact is modelled by *a unique subjobject* classifier which only contains the three different classes that we have mentioned as they serve to build a subobject of a Topos.

Thus a Topos describes correctly a universe of objects that are built on the same stable tradition C.

Proposition: *a Topos is a good model of a creation heritage as all presheafs of the Topos respect the logic of the building category i.e. the traditional know-how of the craft.*

2.3 The generative capacity of C-K/Topos: Concepts as "presheafs that are not sheaves"; Sites as ways to respect tradition

We have now to show how some creative design is possible in a Topos based design theory i.e. in C-K/Topos. In the previous example, what happens if we attempt to design "vegetarian dishes that are in Lux" ? This formulation builds a presheaf on C but we cannot specify the value of this presheaf for all objects of C (since there is no specification for the meat!) i.e. there is no class in the subject classifier that contains such objects. We need to introduce the notion of sheaf that can be defined as a "well formed" presheaf. In Topos theory, a presheaf is "well-formed" (and is then called a sheaf) if the presheaf application preserves specific structures J of objects of C (note that J is itself in C and is, more precisely a specific subobject of Ω). These specific types of subobjects J are called (Grothendieck) "topologies" and the pair (C, J) is called a site.

Topos theory proves that in a given category C, with its given sub-object classifier Ω, there are many such (Grothendieck) "topologies" J, i.e. many sites (C, J). As described below, J defines the "preservation" level for a given tradition C - hence it means that there are different "levels of requirement" in the preservation of tradition. Thus transforming a presheaf (eg "vegetarian lux") into a sheaf on (C, J) , means obtaining a complete design that respects C "in the J way". It corresponds to the transformation of an unknown concept into a known object in C-K theory, with the specific situation that one wants to get a final object that respects C in the J-sense. Thus Topos theory provides us with a clear description of how "respect of tradition" can be built in different ways that all belong to tradition.

Finally, Topos theory predicts that the design of "a vegetarian dish that is in Lux" can be done in two different ways: by classic design strategies (adding knowledge and adapting the category) or by "sheafification" i.e.by innovation within tradition. Let's illustrate these two strategies in the case of the "vegetarian dish".

2.4 Classic design strategies: A "compromise" between tradition and innovation

Consider the "vegetarian dish that belongs to Lux". Three options are possible which correspond to usual "tuning" strategies between tradition and creation[3]:

- **Orthodoxy**: the site J is "demanding" (this is the so-called "coarse" topology), which means that the presheaf application is only applied to "completely defined" subobjects - hence it is impossible to speak of a vegetarian dish without fully describing the sauce and the meat. Since there is no meat in a vegetarian dish, The coarse topology corresponds to a strategy of tradition preservation that will explain that a "vegetarian dish" is *false*, i.e. can't exist in this particular (C, J) : in this particular tradition and with this preservation strategy. With this (C, J) (where J is coarse) the tradition preservation strategy impedes innovation.
- **Local convention - nominalism**: the site J is now "less demanding" (it is for instance a 'dense' topology) - J allows to describe a dish "incompletely". It can be said that J speaks of a dish "from the point of view" of its sauce, without necessarily describing its meat. Still to be well-formed, a pressheaf should enable to clearly identify all the subojects, and in particular the meat, even when the meat was undefined initially. Hence the pressheaf should come with an additional rule that makes that it is possible to determine the "meat" of a vegetarian dish from the chosen sauce. Then the only possibility is *to add a rule* that says that the sauce of the vegetarian dish is a "*type of meat"*. This is a 'local convention' in the sense that it locally extends the "meat" object by adding one (relatively) strange attribute: "vegetarian sauce can be called meat". Tradition is preserved, innovation is confined to a local extension.
- **Innovation**: Finally, we can change the category itself. We consider for instance a category where we say that a dish is characterized by the fact that there is a sauce. We forget about the meat. The scope of creation is now completely open and tradition is broken.

These three cases rejoin classical design strategies that illustrates the "compromise" between tradition and innovation. An important finding is that they can be systematically *deduced* from the structure of the Topos,

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[3] Mathematically, these strategies correspond to the choice of Topology on C that is called a site. The sheafification depends of the site selected.

Proposition: *C-K/Topos models a creation heritage and also predicts classic design strategies that make a compromise between innovation and tradition.*

2.5 Innovation within tradition: How sheafification in a topos revises the definition of objects inside tradition

Now, Topos theory explains and warrants a more interesting process that actually goes beyond the compromise between tradition and innovation. With this process it is actually possible to revise the definitions of objects *inside* a tradition and, even more, *thanks* to the tradition. This is the sheafification technique which at the core of Topos theory. It is not possible in this paper to present all mathematical aspects of sheafification. But there are important theorems that confirm that this operation corresponds to Cohen's Forcing within a Topos {Lawvere, 1964 #3730; Tierney, 1972 #3376}. And we already know that Forcing is equivalent to creative design in C-K theory {Hatchuel, 2013 #2620}. Thus we can establish that in C-K/Topos, sheafification is well defined and describes a rigorous design strategy.
Mathematically, sheafification is a curious process that can be described as such: when a presheaf is not a sheaf in a given Site, it is possible to design a new '*associated'* shief in the same Site. This new sheaf 'extends' the presheaf, which means that it 'contains' the presheaf but it is still a sheaf. Keeping the same site means that:

- i) it keeps the category, hence the tradition;
- ii) it keeps the topology, i.e. the preservation logic of tradition ,
- iii) it controls the "expansion" logic, i.e. it creates a new definition of the objects of the tradition, and extends it while preserving it.

Example : in the case of the "vegetarian dish", the sheafification process will actually lead to define "a meat without meat" (and this goes beyond the 'nominalist' strategy that just named 'meat' a certain sauce). This definition of "a meat without meat" will be made by redefining the notion of "meat" inside the category C while keeping its relations with all the other objects in the category (relation between meat and sauce and between meat and dish) - the process of redefinition of 'meat' requires to study the whole range of possible relationships with each subobject of the system (what does the sauce tells about possible 'meats' -accordance and complementarities in texture, in tastes, in temperatures,…-, what does the 'dish' says about possible 'meats' -general balance, colors, savours, nutriments, etc.-). In the end we can, for instance, redesign the 'meat' as the nutriments and proteins of the dish (in a dietetic tradition!). Note that one can prove that, to generate a new subobject (compatible with the category), the sheafification requires a site that follows the splitting condition (Le Masson *et al*., 2016).
Actually, one can hardly underestimate the paradoxical generative power of sheafification:

- it changes the definition of (sub)-objects of the tradition but keeps the tradition! Hence it is radical innovation still in tradition
- the design of the new identity is actually fully based on the tradition. It is a "rule-breaking" innovation that is based on the rules of the tradition.
- it is a "defixation" (in the sense that it doesn't follow the definition of the objects) that is based on the fixation rules.

Finally, with the sheafification process, C-K/ Topos combines design and tradition in a way that is not a compromise. It allows a new form of innovative design (based on a strong renewal of the definition of objects) that keeps the tradition and is enabled by the tradition.

3 DISCUSSION AND CONCLUSION

3.1 The impact of knowledge structures: Building and teaching a "creation heritage" for designers

The scientific aim of Design theory is to offer a language and models that improve our understanding and provide new methods for teaching or for research. Intuition and common sense tend to oppose tradition and innovation. Our first finding is that the relation between tradition and innovation is much richer and is dependent of two parameters that have been revealed by this research:

i) The structure of knowledge that is associated to tradition: we have seen that tradition contains a fixed set of objects and rules but that the heritage of a craft is not reducible to this unique layer of knowledge. It contains also several layers of knowledge that organize independence and prepare a generative capacity: tradition can contain knowledge about how tradition can change and so on...

ii) a Topos model of knowledge warrants that such generative capacity "respects" a fixed set of objects. It also offers different definitions of "respect" (sites), and some of these definitions allow the existence of an unexpected form of "innovation within tradition", technically modelled by the "sheafification" process.

Consequently, we can rigorously define now with great generality what is a "creation heritage" for designers. Clearly, it is more than a set of past designs, or a fixed set of objects and rules. It has to add to those memories, several other layers of knowledge that prepare generativity and it has to train students to both: i) classic design strategies and ii) to innovation within tradition i.e. reinventing the identity of objects within tradition.

This finding confirms that learning design by projects needs a thorough methodological control (Hatchuel *et al*., 2011b): we have at least to check which design strategies are learned in projects and if necessary, create additional training to teach missing design strategies.

3.2 Beyond Culinary Art: Innovation within tradition as a universal design strategy in systems

The introduction of sophisticated mathematical instruments, like Topos theory requires obust justification. First: we have argued that tradition, heritage, creative design are complex realities in culinary art. Second: such complexity is confirmed by the text books of grand chefs. Third: to overcome complexity we need understandable models which prove our findings, are sufficiently general, and have clear assumptions. This is the traditional role of mathematical models in any science. A specific difficulty in Design science is that the mathematical models which are relevant are not classic ones and do not belong to usual maths for engineers. Hopefully, the findings obtained are worth the effort and we conclude by a brief summary of the important consequences of our findings which also indicate directions for further research.

a) (Hatchuel *et al*., 2013b) already introduced the idea that C-K theory could be seen as a generalization of Forcing to real objects. Actually, the sheafification process generalizes Forcing to universes that are no more Sets. Thus, C-K/Topos appears as a powerful advance in Design theory which is extended to the wide class of objects that are defined by a category C and by all applications from this category to Sets.

b) The whole word of engineered or technical objects can be described by a Topos and all our findings about Culinary Art can be generalized to the world of technical objects. So, what is sheafification in engineering? Technically, sheafification creates a new object that is top-down and bottom up-compatible. This means that it fits with those objects that are dependent of its existence and with those objects that conditions its existence. In engineering terms, this means that interchangeability is warranted towards upper and lower components.

c) Such interchangeability is strategic and relevant for:

- \- Engineering systems where innovation on one part of the system should not destabilize the system itself.
- \- solving the classic opposition between incremental and radical innovation. Sheafification mixes the two notions: the new design is radically different from the old one (creating a vegetarian meat that is now a perfect meat in itself) but the change appears incremental from the point of view of the design heritage (or the system).

d) Finally, studying how innovation can preserve tradition with the highest generality, we have built a model that can be applied to any preservation strategy. The social and environmental implications of such finding are of great importance. We have proved that sheafification techniques are necessary to any design strategies that aim to preserve social and environmental systems. The good news is also that radical innovation is possible even if society and nature have to be preserved! Yet, this achievement depends on our capacity to build knowledge structures about these systems that fulfil all the properties of a creation heritage. Fortunately, thanks to topos theory, these conditions are now rigorously understood and established.

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APPENDIX: EL BULLI MANIFESTO

In the mid-1990s a new style of cuisine began to be forged. Today, this style has been wholly consolidated and may be defined in the following terms:

1. Cooking is a language through which all the following properties may be expressed: harmony, creativity, happiness, beauty, poetry, complexity, magic, humour, provocation and culture.
2. The use of top quality products and technical knowledge to prepare them properly are taken for granted.
3. All products have the same gastronomic value, regardless of their price.
4. Preference is given to vegetables and seafood, with a key role also being played by dairy products, nuts and other products that make up a light form of cooking. In recent years red meat and large cuts of poultry have been very sparingly used.
5. Although the characteristics of the products may be modified (temperature, texture, shape, etc.), the aim is always to preserve the purity of their original flavour, except for processes that call for long cooking or seek the nuances of particular reactions such as the Maillard reaction.
6. Cooking techniques, both classic and modern, are a heritage that the cook has to know how to exploit to the maximum.
7. As has occurred in most fields of human evolution down the ages, new technologies are a resource for the progress of cooking.

8. The family of stocks is being extended. Together with the classic ones, lighter stocks performing an identical function are now being used (waters, broths, consommés, clarified vegetable juices, nut milk, etc.).
9. The information given off by a dish is enjoyed through the senses; it is also enjoyed and interpreted by reflection.
10. Taste is not the only sense that can be stimulated: touch can also be played with (contrasts of temperatures and textures), as well as smell, sight (colours, shapes, trompe d'oeil, etc.), whereby the five senses become one of the main points of reference in the creative cooking process.
11. The technique-concept search is the apex of the creative pyramid.
12. Creation involves teamwork. In addition, research has become consolidated as a new feature of the culinary creative process.
13. The barriers between the sweet and savoury world are being broken down. Importance is being given to a new cold cuisine, particularly in the creation of the frozen savoury world.
14. The classical structure of dishes is being broken down: a veritable revolution is underway in first courses and desserts, closely bound up with the concept of symbiosis between the sweet and savoury world; in main dishes the "product-garnish-sauce" hierarchy is being broken down.
15. A new way of serving food is being promoted. The dishes are finished in the dining room by the serving staff. In other cases the diners themselves participate in this process.
16. Regional cuisine as a style is an expression of its own geographical and cultural context as well as its culinary traditions. Its bond with nature complements and enriches this relationship with its environment.
17. Products and preparations from other countries are subjected to one's particular style of cooking.
18. There are two main paths towards attaining harmony of products and flavours: through memory (connection with regional cooking traditions, adaptation, deconstruction, former modern recipes), or through new combinations.
19. A culinary language is being created which is becoming more and more ordered, that on some occasions establishes a relationship with the world and language of art.
20. Recipes are designed to ensure that harmony is to be found in small servings.
21. Decontextualisation, irony, spectacle, performance are completely legitimate, as long as they are not superficial but respond to, or are closely bound up with, a process of gastronomic reflection.
22. The menu de dégustation is the finest expression of avant-garde cooking. The structure is alive and subject to changes. Concepts such as snacks, tapas, pre-desserts, morphs, etc., are coming into their own.
23. Knowledge and/or collaboration with experts from different fields (gastronomic culture, history, industrial design, etc.,) is essential for progress in cooking. In particular collaboration with the food industry and the scientific world has brought about fundamental advances. Sharing this knowledge among cooking professionals has contributed to this evolution.

A LAW OF FUNCTIONAL EXPANSION - ELICITING THE DYNAMICS OF CONSUMER GOODS INNOVATION WITH DESIGN THEORY

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ABSTRACT

For more than two decades, mobile phone industry has shown that innovation is not only functional optimization and combination but can also be a "functional expansion". Sometimes called radical or disruptive innovation, this phenomenon leads to the development of new method for engineers and designers. However, the intensity remains undemonstrated: is functional expansion a rare phenomenon (few products during very short periods of time) – or is it an intense phenomenon, that even might have accelerated in the last decades? To answer these questions, the paper overcomes two main obstacles: how to measure functional expansion? And what would be a law of functional expansion, that would enable to test the importance and newness of the phenomena? Building on recent advances on the measurement of innovation and on new computational models of design derived from most advanced design theories, this paper presents unique data on functional expansion of 8 consumer products and tests that functional expansion significantly accelerated in the mid 1990s. The paper confirms quantitatively that our societies are now in a new design regime, a regime of innovative design.

Keywords: Design theory, Innovation, Functional expansion, Technology

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1 INTRODUCTION

For more than two decades, mobile phone industry has shown that innovation is not only functional optimization and combination but can also be a "*functional expansion*", ie it consists in regularly, repeatedly *inventing new functions for products*: over the last decades, the phone became a 'smart phone' with surprising new functions. This phenomenon of functional expansion is also analysed as 'disruptive innovation' (Christensen 1993, 1997) or 'radical innovation' (O'Connor 1998). For engineering design, this is a critical phenomenon, since the design of functional expansion requires new methods, coming and adding to the well-known methods of functional combination and optimization (Le Masson *et al*., 2017).
However: is this phenomenon so strong? Maybe it is just one type of products that is hit by this phenomenon, maybe functional expansion just happens once or twice on certain products and maybe functional combination and optimization still largely dominates the realm of product design? This would be the so-called "Lancasterian" hypothesis: Kelvin Lancaster is a very famous economists who, in the 60s, wondered how the general equilibrium model of economics, at that time based on the hypothesis of a finite (fixed) list of products, could be adapted to account for the phenomena of regular renewal of products that was already largely visible in the 60s, a time of mass-diversity and regular evolutions of mass consumption products. Lancaster saved the general equilibrium by proposing a theory (Lancaster 1991; Lancaster 1966) based on the hypothesis that product performances increase but each product has a stable set of function that defines it. Doing so he could rewrite the equations of general equilibrium on the set of (fixed) performances. This was a great success in economics. But this result is based on the hypothesis that there is no functional expansion. And to our knowledge, no studies were ever launched to check this hypothesis. By contrast, for some authors, this phenomena of "functional expansion" is a unique and specific feature to characterize contemporary innovation (Le Masson *et al*., 2010; Witt 2009; Becker *et al*., 2006); according to these authors, it is a phenomenon that is particularly visible on mobile phones but might also exist on other products; and it is a phenomenon that would have significantly increased in the last decades. Hence our research question: is the phenomena of functional expansion visible over long time period and on different products? And does this phenomenon increase significantly in the 1990s?
Testing these hypothesis raises critical issues: in case of functional optimization and combination engineering design can rely on several predictive models; when it comes to functional expansion, even basic elements are missing: 1) it is not self-evident to just roughly evaluate the phenomena of functional expansion. One can generally agree that the mobile phones changed to become "smarter" - but can one measure the level of functional expansion? Can one compare functional expansion on mobile phone with functional expansion on other products? 2) it is difficult to propose a reasonable predictive model because we don't know what might be relevant predictive variables. We need to relate the process of functional expansion to specific engineering resources and build a simple predictive model that would account for functional expansion, ie we need a so-called "law of expansion". If one would have a measure of functional expansion and this law of expansion, then it could become possible to test whether functional expansion significantly evolved in the last two decades.
Hence the program of this paper is as follows: building on existing literature, we will propose a way to measure functional expansion; building on recent advances in design theory, we will be able to propose a law of expansion; applying the law of expansion to our data of functional expansion, we will test whether there was a significant increase in functional expansion in the last decades.

2 LITERATURE REVIEW AND RESARCH QUESTION: FUNCTIONAL EXPANSION AND CHANGES IN DESIGN REGIMES

2.1 Measuring functional expansion

Over time, research on innovation analysed specific types of innovation. In early 20th century, innovation was associated to productivity, and political economists measured the productivity in steel industry or in coal mining. In mid-twentieth century, one rather measured the diffusion of innovation with equipment rates; one also measured functional performance increase (decrease in fuel consumption, increase in safety, comfort,…). Since contemporary innovation seems to consist also in functional expansion, we need to develop a new instrument. Note that this instrument was actually suggested by a Kelvin Lancaster himself, who explained how his hypothesis should be tested (Lancaster 1991; Lancaster 1966). Building on Lancaster, the requirements for the measurement are as follows (and are quite demanding):

a) requirement 1: one measures "functions" in the sense of "reason to buy" - so many 'technical functions' should be ignored as long as they are not 'existence conditions' for a product on a market. Lancaster call them "product characteristics that have an economic effect". These are the "purchase" criteria that a buyer should you to maximise his/her utility function.

b) requirement 2: since it is difficult to access to all products of a certain family on a given market (all mobile phones on the French market at time t1), there is a sampling issue: how to sample all the products of a certain family on a certain market at time t1; and the sampling process must be stable over time.

c) requirement 3: the method has to be stable over time; there are two apparently conflicting requirements here: one has to avoid "anachronism" effects in which an observer of time t2 judges the emergence of function at time t1, t1<<t2; and this calls for "synchronous" observers (observation of functional changes at time t1 is made by an observer present at time t1); but one has to avoid too strong "subjective" differences so observers at time t1 and t2 have to share common criteria to evaluate the functional emergence.

One solution suggested by Lancaster is to rely on consumer reports. One can explain this suggestion:

a) consumer reports are "utilitarian" by construction: they claim to only focus on "pure" functions, avoiding fashions or so called "technical functions" that only technical experts could understand and value. Hence it meets requirements 1. Note that they will tend to "underestimate" functional expansion since they ignore some functions that might be a "function" for a few buyers. Note also that they are supposed to be independent from product designers.

b) consumer reports are companies or association that build on all the marketing knowledge for a given family of product on a given market for a given period of time. Hence they have developed a sampling capacity. Note that, as independent prescribers, they are supposed to control for possible biases (brand or company biases) in the sample. Hence they meet requirement 2.

c) consumer reports are companies and association that are stable over time: they make regular evaluation over time, hence there is a "synchronous" measurement; and they have well-established rules that are kept stable over time to evaluate what is a function - hence this is a synchronous and yet objective measurement instrument. Hence they meet requirement 3.

Recent works have helped to develop a new method for measuring functional expansion at an industry level based on consumer reports (El Qaoumi *et al*., 2017). These works have already largely validated the method. The measurements made on 4 types of products led to prove in particular that Lancaster was wrong. In this paper we built on the same method, relying on a larger set of products (we increase the data base to 8 families of products).

2.2 A model of functional expansion

What are the available models to account for functional expansion and functional combination? It is well-known that the existence of a new product will depend on customer acceptance (in a 'demand side' perspective) or technical discoveries (in a 'supply side' perspective). These approaches (detailed for instance in (Arthur 2009; Saviotti 2001; Saviotti and Metcalfe 1991; Nelson and Consoli 2010)) have taught us that a new product will require knowledge creation, either from the science point of view (knowledge creation for making discoveries and designing a new technique) or from the market point of view (knowledge creation to design new usages of the new product). *Hence a model of functional expansion should depend on the overall effort put on designing (the techniques and/or the usages)*. Hence the *design effort* is a first dimension that should characterize a design regime. Some authors went as far as considering that this single should be enough and propose, for instance, a Poisson law for the emergence of new products or new techniques where the Poisson parameter is proportional to R&D investment (see (Aghion and Howitt 1992), an endogenous growth model). But this model was considered as too simple and not empirically confirmed (Jones 1995).

A critical limit of a Poissonian model is that it considers that the events are independent - whereas many works have underlined that existing techniques might have more or less generic effect, ie enable more or fewer combinatorial applications, depending on the set of already existing technologies, the knowledge heritage. This logic of higher or lower generativity is illustrated by the works of Fink *et al*. (Fink *et al*., 2017) showing that in situations of "combinative" innovation, some new building blocks can have a much higher generative power than other (Fink *et al* paper relies on three combinative situations where a new 'component' enable a certain number of new 'products': how a new letter added to a given list of letters enables to create new words; how a new ingredient added to a list of ingredients enables to create new recipes; how a new software development tools added to a list of software development tools enables to create new software). This model corresponds to so-called "generic"techniques (Kokshagina 2014; Bresnahan and Trajtenberg 1995) that can have an impact on several markets and applications, hence having much higher "generativity" power than a non-generic one. Hence the model of functional expansion should integrate the issue of genericity of the newly created function. It means that there is an "heritage" that determines the potential of future functional expansion. This is not only a "path dependency" (David 198, in the sense that it does not only describe the limits and restrictions to expansion but describes also the potential of future expansions.

How can one model this "heritage" of techniques that would determine expansions? It is today well-known that the logic of lower and higher genericity depends on *the structures of techniques and the interdependencies between techniques*: in the so-called C-K/Ma model, (Le Masson *et al*., 2016) model a system of techniques by the interdependences and is able to account for the expansion of systems of techniques. The paper also proposes a computable model that predicts the dynamics of a system of interdependent techniques. Hence C-K/Ma can lead to *propose a law of functional expansion parameterized by the design effort and taking into account the "heritage" of techniques that determine the potential of functional expansion*.

2.3 Research questions: characterizing design regimes and their evolutions

Based on the literature we have a measurement technique to measure functional expansion and we have building blocks to propose a law of functional expansion. In this paper we fit this law with the empirical data. *Our first research question is to check whether the law fits with the empirical data.*

Moreover, if there is a fit, this fit will reveal the design regime associated to the functional expansion. Hence it will be possible to test whether there is a significant change in the design regime over time. *Our second research question is hence to check that there is a change in the design regime - and check whether this change occurred in the mid 90s.*

We now build a law of function expansion in design regimes. We then present the empirical material and proceed to the tests.

3 A LAW OF EXPANSION IN DESIGN REGIMES

3.1 Principles of C-K/Ma

We build our law on the C-K/Ma model (exposed in (Le Masson *et al*., 2016)). In this model, a technique is an element of a matroid. The structure of techniques is the matroid of techniques. A product is called a "working system", it is made of techniques that 'work together', techniques that can be said 'compatible', which correspond, in matroid terms, to a circuit. If we consider a graphic matroid G, the elements are edges; each technique is an edge ti, E = E(G) is the set of edges of the graph; a working system (a product) is a circuit and in a graph, a circuit is actually a path made of edges (techniques) that is connected and all vertices are of degree 2, ie the circuit foes only once through each vertex (see figure 1 below).

In this model, what is a function? It is both a property of a product and the effect of (at least) one function. In a graph, *one can assimilate a function to a vertex that is on a circuit*: a vertex on a circuit can be associated to two techniques and is an element of a product. The vertices of the graph are V(G). In (Le Masson *et al*., 2016), the authors use the example figure 1 below: the graph G below can be interpreted as a synthesis of the technological know-how of a designer. The designer knows how to address {f1; f2; f3} (with the circuit t12-t23-t31); he doesn't know any solution to address {f1; f4}. A matroid can be associated to this graph of designer's knowledge, the matroid defined by the cycles of the graphs. In this matroid {t12; t13} is independent whereas {t12, t13, t23} is dependent. {t12, t45} is also independent.

The matroid representation has the first advantage to focus on the interdependencies inside a structure of techniques and to characterize all the known combinations that correspond to a product (all the cycles in the matroids). It also provides a critical quantifier: a matroid has a certain rank which actually corresponds to the size of the largest independent set. In a graph G, we have the rank function r(G) = |V(G)|-1. (r(G)=4 in the example below), where |V(G)| is the number of vertice.

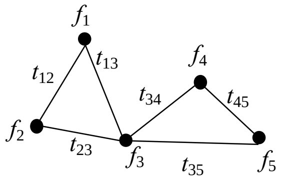
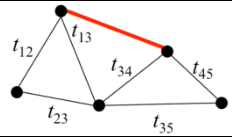
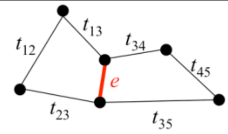


Figure 1: A graph G

C-K/Ma models the design of a new matroid from a given one. The paper shows that the design of a new system of techniques actually relies on two main operations (see table below):

- The extension, that consists in drawing a (dependent) edge between two existing functions to create a new circuit. This operation corresponds to a new product (working system) that is exactly the new combination of known functions. The impact of the extension on the structure of techniques is as follows: it doesn't change the rank r of the matroid; it decreases (by minus 1) the number of remaining possible combinations not done yet. Hence it decreases the potential of functional combination associated to the known techniques. Note that an extension is not possible if the matroid is said complete: this corresponds, in a graphic matroid, to the situation where there is an edge between any pair of vertices.
- The co-extension, that is less intuitive, and corresponds to a new independent edge common to several connected components. This operation corresponds to designing a generic technique, generic to several technical families. It adds one new function - this operation is the unique operation that enables functional expansion. In matroid terms, a co-extension corresponds to an extension made on the dual of the matroid. The impact of the co-extension on the structure of techniques is as follows: it increases the rank r of the matroid (by +1) ; it increases (by r) the number of remaining possible combinations not done yet. Note that, surprisingly enough, a co-extension is not possible if the dual of the matroid is complete.

Table 1. Main design operations in the dynamics of technique and in matroid (last colomn: illustration on the graph G of figure 1)

Cumulative design of working systems with new technique linking other techniques and minimizing propagations	*Extension* ie one dependent edge, depending on the techniques to be linked together	
Designing a generic technique, generic to several technical families	*Coextension* ie one independent edge common to several connected components	

3.2 Relying on C-K/Ma to build a law of expansion in design regimes

Let's now begin to model a design regime: given a certain product type T, we associate to T the set of techniques that enable to design the existing products. Techniques used in a known product are said dependent. The techniques are defined so as to meet the axioms of matroid (in (Le Masson *et al.*, 2016), the authors explain how to describe a structure of technique to meet the axioms of matroid theory). We suppose that the resulting matroid is graphic. To each edge of the matroid, we associate a function. This defines the initial rank, r0, of the matroid M of techniques of T.

We now design a new technique. Unless the matroid is complete, an extension is possible. Unless the dual is complete, a co-extension is possible. These operations can be repeated. In the repetition, a constraint emerges: extensions or coextensions, enabled alone, lead to deadlocked systems since extension leads to complete the matroid and co-extension leads to complete its dual. Hence a direct consequence demonstrated in (Le Masson *et al.*, 2016): "*the only way to get an unlocked dynamic consists in combining extension and coextension – ie the combination of the design of working systems and the design of generic techniques*".

This key property enables to identify several design regimes, and two of them deserve particular attention: the 'extension-driven' and the 'co-extension' one.

1- The "*extension-driven" regime* gives priority to extension (the design of working systems). In this regime, co-extensions (the design of generic techniques) are as rare as possible. Over time the matroid becomes complete and no extension is possible anymore. Hence one co-extension is required, it increases the rank by +1 (the rank becomes r0+1) and the generativity by +r0. Over time the rank increases slowly: one co-extension that increases the generativity by r0 and the rank with +1, then r0+1 extensions until generativity decreases to 0 and again co-extension, this time with the rank r0+1, then r0+2 extensions, etc. *In this regime, the creation of generic technique is "endogenous"*, in the sense that the internal logic of the extension of techniques pushes to 'invent' a new technique that changes the game. This contrasts with a logic where co-extension appears without the internal 'pressure' of extension (see below). Note that this can describe regimes with "low" functional generation or "high" functional generation" - this will mainly depend on the intensity of the design effort (see Next and Ncoext in equations 1 and 2 below).

In this regime, one can write the law of extension: at time t, the rank is r(t), at time 0 it is r0. At time 0, r0 extensions are possible. At time r0+1 a co-extension is required and the rank becomes r0+1. And so on. Hence at time (r0+1) + (r0+2)+…. + (r0+k) the rank is r0+k (see Figure 2 below).

Hence the equation:

$$r\left(k.r_0+\frac{k.(k+1)}{2}\right)=r_0+k$$

Hence $r(t)=r_0+k(t)$ with $t=\frac{k^2}{2}+\left(r_0+\frac{1}{2}\right).k$. There is one positive root for this equation:

$k=\sqrt{(r_0+1/2)^2+2t}-(r_0+1/2)$. Hence the general equation:

$$r(t)-r_0=\sqrt{(r_0+1/2)^2+2t}-(r_0+1/2).$$

If there is N_{ext} new techniques created per unit of time in this regime, then the equation becomes:

$$r(t)-r_0=\sqrt{(r_0+1/2)^2+2N_{ext}t}-(r_0+1/2).$$

If $N_{ext}t \ll \frac{r_0^2}{2}$, then $r(t)-r_0\approx\frac{N_{ext}t}{\left(r_0+\frac{1}{2}\right)}$; If $N_{ext}t \gg \frac{r_0^2}{2}$, then $r(t)-r_0\approx\sqrt{2N_{ext}t}$ (see figure 2).

Note that this law supposes that the matroid is fully completed. We could have a variant with a "saturation" at level rmin or at a fraction β of the full completion. In the first case: this consists in replacing r0 with r0-rmin. In the second case the fraction β shortens the time to reach completion, hence:

$$r(t)-r_0=\sqrt{(r_0-r_{min}+1/2)^2+2N_{ext}\beta t}-(r_0-r_{min}+1/2). \quad (1)$$

Or: $(r(t)-r_{min}-1/2)^2-(r_0-r_{min}-1/2)^2=2N_{ext}\beta t$, linear in t. (1')

2- Conversely, the "co-extension-driven" regime favors co-extensions. We have then a symmetrical situation: a hand of dependent systems and many independent techniques. In that case the invention of a generic technique is not driven by the internal constraint of the system of techniques. Hence this is an *exogenous creation of independent techniques*. Note that over time, an extension becomes necessary to make an additional co-extension. This constraint implies a law on the "co-extension driven" regime: we have the following relation:

$r\left(k.r_0^*+\frac{k.(k+1)}{2}\right)=r_0+k.r_0^*+\frac{k.(k+1)}{2}$ where r* is the rank of the dual of the matroid.

Hence $r(t)-r_0=t-k(t)$ with $t=\frac{k^2}{2}+\left(r_0^*+\frac{1}{2}\right).k$.

Hence we have:

$$r(t)-r_0=t-\left[\sqrt{(r_0^*+1/2)^2+2t}-(r_0^*+1/2)\right].$$

If there is N_{coext} new techniques created per unit of time in this regime, then the equation becomes:

$$r(t)-r_0=t-\left[\sqrt{(r_0^*+1/2)^2+2N_{coext}t}-(r_0^*+1/2)\right]. \quad (2)$$

If $N_{coext}t \ll \frac{r_0^{*2}}{2}$, then $r(t)-r_0\approx N_{coext}t$; If $N_{coext}t \gg \frac{r_0^{*2}}{2}$, then $r(t)-r_0\approx t-\sqrt{2N_{coext}t}$ (see figure 2).

Note that, contrary to what appears on figure 2, r_0^{*2} is usually relatively big: in a matroid M we have $r^*+r=|M|$ where $|M|$ is the number of elements in the matroid (ie edges for a graphic matroid) -

when M is complete the magnitude of $|M|$ is in the order of $r_0^{\ 2}$ so the order of magnitude of r_0^{*2} is $r_0^{\ 4}$. Hence a very steep slope for the exogenous curve below.

3.3 Conclusion: a law to characterize functional expansion

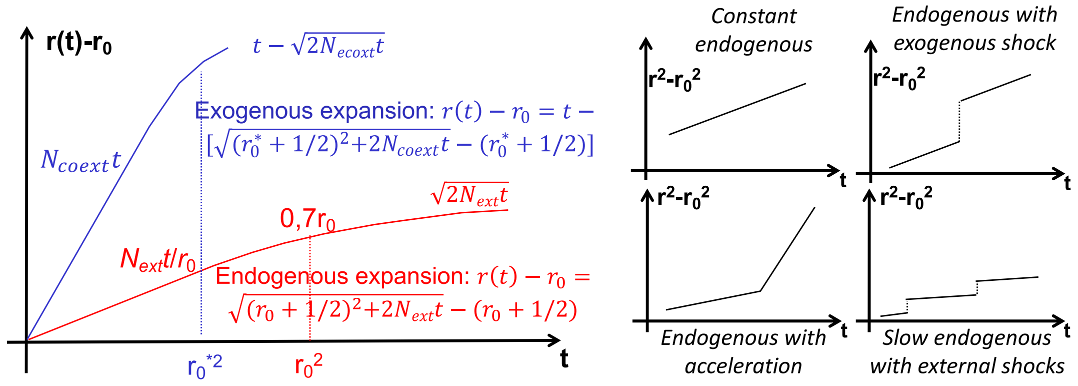


Figure 2: models of functional expansion (left graph: "pure" exogenous (blue) and "pure" endogenous cases (red); right: four mixt cases, represented on the anamorphosized data).

In the model above (eq. 1'), *a design regime can be characterized as a base of endogenous expansion with occasional exogenous expansion*. An endogenous expansion is characterized as a straight line in the graph $(r(t)-r_{min}-1/2)^2-(r_0-r_{min}-1/2)^2$ vs t, and its slope $2N_{ext}\beta$ relates to the design effort. A very low slope relates to an almost *pure functional combination (almost no expansion).* A positive break in the slope indicates an *intensification of the design effort* (change in the design regime). The endogenous regime can punctually be enriched by non-endogenous expansions. This creates a jump, *a break in the curve with a constant slope* (see figure 2).

4 TESTING THE LAW ON EMPIRICAL DATA

4.1 Material: empirical data on functional expansion

We used the archives of the French Consumer Report Que Choisir. We followed 8 types of products (see below) and we had access to integral archives of each product study of the period below.

Table 2. Sample: 8 consumer products, time period and number of studies during the period

Type of product	Period	Number of studies
Iron	1962-2014	24
Vacuum Cleaner	1969-2014	37
Freezer	1970-2014	17
Refrigerator	1973-2014	21
Toothbrush	1975-2014	7
Bicycle	1975-2014	13
Mobile phone	1996-2014	24
GPS	2007-2014	10

For each product, we compare the functions in the new test at time t+1 with all the functions that appeared in the test between time 0 and time t. If the function is semantically (significantly) different we consider it as new. We had a double (in certain cases triple) coding. We represent the result on the graph below (aggregated new functions until the date of the study vs date of the study, figure 3).
This graph calls for some comments:

- There is, for the 8 products, a visible functional expansion. Even the toothbrush shows regular creation of functions. The slowest functional expansion is the refrigerator.
- The fastest expansion is the smart phone - this is coherent with the intuition we mentioned in our introduction. It created 113 new functions in 18 years. Less intuitive is the fact that the vacuum cleaner created more functions (124) than the mobile phone, even if on a longer time period (46 years).

- This tends to invalidate Lancasterian hypothesis: there is a functional expansion on many products, not only on smart phones. We need to test it.
- Regarding our second hypothesis: it is less self evident that there is a regime change in the 90s even if it seems that there is a break in the design of vaccum cleaner around 1992, a break for Iron around 1995, a break for bike around 1995. This also needs to be tested.

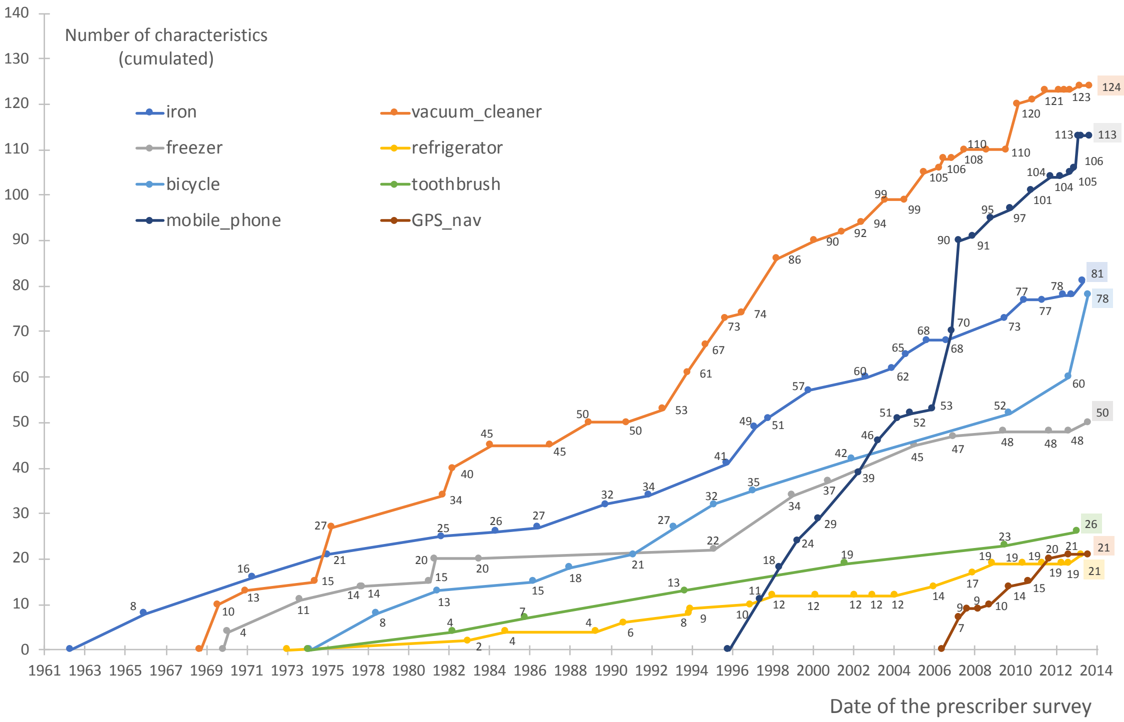


Figure 3: Empirical measurement of functional expansion on 8 consumer goods (w axis: time; y-axis: cumulated number of characteristics). Ex: in 1971, after the third study on vacuum-cleaner, the product vacuum-cleaner has gained 13 additional functions since the first study (done in 1968)

4.2 Result: fit of the law of functional expansion and change in functional expansion.

We fit the graphs of measurement vs time with the law of endogenous expansion. For the reader, we represent below the anamorphosized data (on y axis: $(r(t)-1/2)^2-(r_0-1/2)^2$) (figure 4).

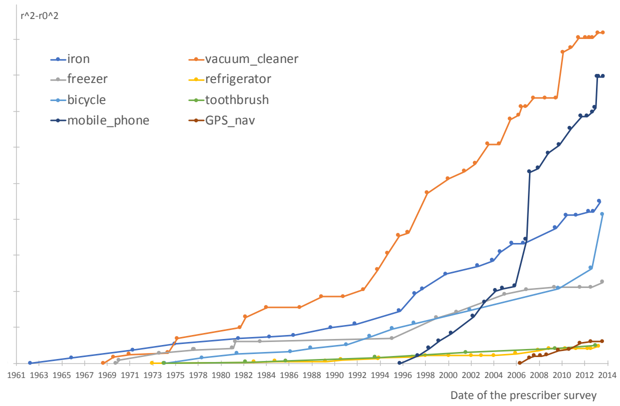


Figure 4: $(r^2-r_0^2)$ vs time: the breaks of slope and the jumps in the curves are more visible

For each product, we fit the endogenous expansion model (eq. 1') and estimate the slope as follows: for each product we conduct a regression on the all period, then we conduct a Chow test on all possible break dates to identify possible significant breaks in the regime. For each significant break we characterize the two regressions (before and after the break) and we check whether the slopes are significantly different (confidence interval at 95% level). In that second case, it means that the break in linear regression is a jump. The results are summarized in table 3 and below:

- Four products follow a model of endogenous expansion with a significant slope break: iron, vacuum cleaner, freezer and bicycle (the latter without outlier 2014). In a first phase there is slow endogenous expansion then a stronger one. The slopes ratios and dates are: 2,6 (freezer, in 1995-1999), 3,3 (bicycle; in 1991-1993), 3,66 (vacuum cleaner in 1993-1994) and 4,47 (iron in 1992-1996).
- One product follows a strong endogenous expansion with a jump: the mobile phone. The slope is very high (between 565 and 786). There is strong jump (in 2006-2008), without significant change in slope. It corresponds to the first "smart phones", that implied a strong change in the technologies (Glimstedt 2018).
- Two products follow a constant endogenous expansion: toothbrush and GPS. The toothbrush has one of the lowest slope (28,7); the GPS is relatively high (around 151).
- One product follows a very slow endogenous expansion: the refrigerator (slope around 25, with long periods of no changes in the functions, which explains why the regression is less significant). There is at least one testable jump (around 2006-2008; no significant change in slope) which can be considered as an exogenous expansion in a very slow endogenous expansion. This corresponds to the (well-known) fact that innovation on this product is largely driven (and constrained) by energy consumption, hence the very limited functional expansion.
- Additionally, one can notice other jumps on some curves: a jump in 2011 on vacuum cleaner (robot vacuum cleaner), a jump in 2014 on bicycle (electric bike). There is a (light) jump in 2014 in mobile phone related to a strong enrichment of camera functions.

Table 3. Results

	a	t_stat	Chow	p-value	a-before	p-value	conf int 95%	a-after	p-value	conf int 95%	Slope break
iron	197,99	***	1992-1996	2.10-14	68,2	***	[58; 78]	305	***	[284; 326]	yes
vacuum cleaner	461,41	***	1993-1994	2.10-16	176	***	[150; 201]	644	***	[610; 677]	yes
freezer	100,8	***	1995-1999	0,001	46,9	**	[22; 71]	121,9	***	[80; 164]	yes
bicycle (2014 outlier)	140	***	1991-1993	0,001	53	**	[33; 73]	175	***	[141; 209]	yes
mobile phone	1015,8	***	2006-2008	3.10-9	565	***	[439; 691]	786	***	[620; 951]	no
GPS	151,7	***	no								
toothbrush	28,7	***	no								
refrigerator	27,7	***	2006-2008	6.10-5	20	***	[17; 23]	26,9	*	[1; 52]	no

With these results, we can conclude on our research questions:

- Research question 1: a regime of functional expansion is present in all products. - at a very low pace for refrigerator or toothbrush; at a surprisingly high pace for vacuum cleaner or iron. And, as expected, at the highest pace for mobile phone. This means that even if irons or vacuum cleaners seem to remain "the same" over time, the reasons to buy them have significantly changed for the last decades.
- Research question 2: for the 6 products with long life time, 4 on 6 show a significant change in slope and this change in slope occurs in the 1990s (the earliest: bicycle 1991-1993, then vacuum cleaner 1993-1994, then iron 1992-1996, and finally freezer 1995-1999). The refrigerator and the toothbrush don't show a significant change in slope.

5 CONTRIBUTION AND DISCUSSION: 'DESIGN-METRICS' AND DESIGN HERITAGE

To conclude: this paper shows that *it is possible to predict a law of functional expansion of products and this law was successfully tested on a sample of 8 consumer products*. Contributions are as follows:

- We prove that functional expansion is not limited to mobile phone - it exists for all the tested consumer products.
- We prove that functional expansion significantly accelerated in 1990s.

Confirming the intuition of functional expansion, this work suggests that we are in a non-Lancasterian economy, an economy of functional expansion, hence it underlines the need to prepare the designers (engineering design as well as industrial design or architectural design) to functional expansion and not only to optimization. This is also important for managers of innovation management.

Moreover this work is a first step towards a "*design-metrics":* we have relatively few methods to measure innovation; and we have even less when it comes to measure expansion. It is already quite difficult to measure an "increase" (or decrease) of a functional performance; we can't underestimate the difficulties to measure the emergence of new dimensions. This work paves the way to further research on measuring expansion of products. We have today many techniques of measurement in "econometrics" - but these techniques focus on optimization into a stable frame of references - they ignore generativity. If the expansion becomes critical for competition, we need today new methods and tools to measure and predict it. This calls for the development of a 'design-metrics', a discipline that would try to measure contemporary phenomena of design generativity, that are largely ignored by "econometrics" and could become critical for our societies.

Finally, this work also leads to a critical theoretical result: the empirical data confirm a model of "endogenous functional expansion" and this means that functional expansion, that is deeply related to "disruptive" innovation, actually relies on an "*heritage" of previously designed techniques* that actually determines the potential of future expansions. This heritage is more than a "path dependency" in the sense that it does not "reduce" the possibilities but it actually 'creates' them. And this heritage can be characterized by the interdependence structure of its elements. This result doesn't exclude exogenous shock but it reminds that endogenous logics can be very powerful and can explain contemporary logic of functional expansion.

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Axe 2 : Pilotage de la conception et gouvernance de l’entreprise innovante

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THE HIDDEN FEAT BEHIND DEVELOPMENT COST ESCALATION - HOW ENGINEERING DESIGN ENABLES FUNCTIONAL EXPANSION IN THE AEROSPACE INDUSTRY

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ABSTRACT

The aerospace industry experiences a considerable growth in product development costs. Many research works aim at identifying evolution laws characterizing this large-scale phenomenon and at developing design strategies which could help mitigate it. This paper aims to clarify the evolution dynamics governing this phenomenon by studying how the products delivered by these costly projects evolve with time. Increasing complexity is often held responsible for surging costs. If complexity is generally defined as the price to be paid for improving product functionalities, it is rarely specified whether the improvement affects existing functionalities or involves new ones. We aim to identify the patterns of cost growth which can be associated with phenomena of existing functionalities upgrade and new functionalities introduction, and to identify the associated design capabilities that designers need to deploy in order to keep product change and cost growth under control. To that end, we introduce a model which generates curves, each of which featuring a trend of cost growth, specific to a scenario of product evolution and being interpretable as a signature of a strategy used by designers.

Keywords: Design costing, Functional modelling, Product architecture, Innovation, Functional expansion

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1 INTRODUCTION

Over the last decades, the aerospace industry has been experiencing a considerable increase in product development costs. A famous example of this phenomenon is Norman Augustine's (1983) law (The Final Law of Economic Disarmament), according to which, the entire American defence budget will be consumed from buying one military aircraft by 2054, if the increasing trend persists. Commercial aircraft development programs are also subject to a phenomenon of cost escalation, as steadily increasing development times (from program launch to Entry Into Service (EIS)) reveal (be it in the case of full developments as illustrated in Figure 1 (JMDLV ©) or derivative aircraft). (The development costs associated with increasing development times escalate accordingly).

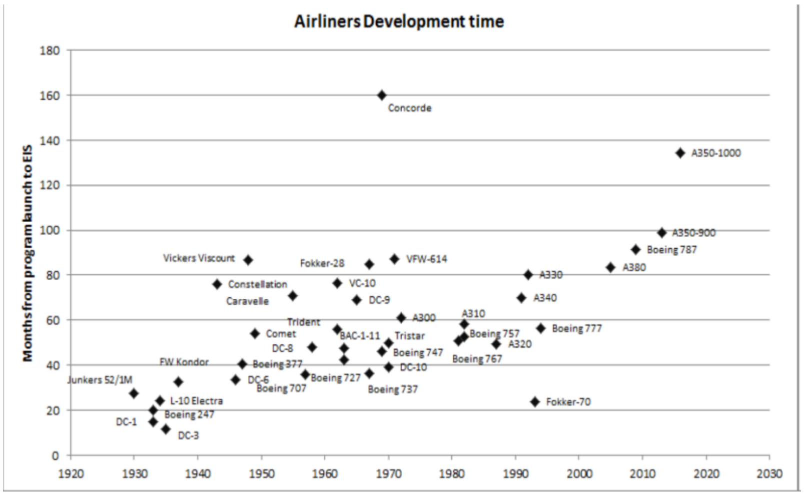


Figure 1. steady growth in commercial aircraft development times (JMDLV ©)

Representing a possible threat to the profitability of the projects, programs and even firms associated with these costs (Winter, 2015), this phenomenon appears alarming and symptomatic of engineering departments having lost control over new product development. Therefore, many research works and studies aim at grasping the reasons for this growth, i.e. at identifying the laws, the patterns of the increase, the driving forces… characterizing this large-scale phenomenon (Arena *et al*., 2008 ; Stuart *et al*., 2011 ; Hove and Lillekvelland, 2015) and at developing design strategies and tools which could help slow it down and mitigate it (de Weck, 2012).
This paper aims at investigating and characterizing the challenges faced by engineering departments in order to assess the extent of the 'loss of control' at issue. To that end, our approach consists in clarifying the evolution dynamics governing this cost escalation phenomenon by studying how the products, i.e. the outputs delivered by these costly programs and projects evolved with time.
Section 2 reviews the laws characterizing product evolution dynamics, in terms of complexity (Carlson and Doyle, 1999, 2005 ; Sinha, 2014) and functional expansion (that is an increase in the number of functionalities fulfilled by consumption goods) (El Qaoumi, 2016). Our objective is to identify the patterns of cost growth which can be associated with evolution phenomena occurring at product level, as well as the capabilities that designers need to deploy in order to keep these phenomena under control. Therefore, Sections 3 and 4 propose a model which generates the cost growth patterns associated with specific scenarii of product changes implemented with specific design capabilities. Then, in the face of cost growth patterns observed in real cases, this model can diagnose which aspects of product change were more or less kept under control by designers. This enables to (re)interpret cost growth phenomena such as the one presented in introduction. We discuss these results in Section 5.

2 LITERATURE REVIEW

This section aims at reviewing the literature related to product evolution dynamics, in an attempt to see how it can help interpret costs escalation phenomena.

2.1 Product change and complexity

Technical systems growing complexity (Spinney, 1980; Carlson and Doyle, 2002; DARPA, 2008; Stuart *et al*., 2011 ; Sinha, 2014 ; Hove and Lillekvelland, 2015) is widely associated with escalating costs. The notion of increasing complexity plays an important role in product evolution. Indeed, when implementing products changes (specified in the form of modified or new product requirements), designers must handle three major aspects of complexity (uncertainty, interconnectedness, and emergence). Firstly, dealing with complexity involves dealing with *uncertainty*, since complexity can be defined as “a measure of uncertainty in understanding what we want to know or in achieving a functional requirements (Suh, 2005). According to Suh’s information axiom, efficiently handling complexity involves seeking to maximize the probability of satisfying the functional requirements (i.e. minimizing the information content) (information axiom). Dealing with complexity also involves managing *interconnectedness*, i.e. the *interactions* between the heterogeneous elements of a system. And according to Suh’s (2005) independence axiom, the best design is the one which minimizes the level of coupling between the functional requirements. The notion of complexity also includes a phenomenon called *emergence*, which involves both uncertainty and interactions. Emergence phenomena (Alderson and Doyle, 2010 ; Carlson and Doyle, 2002) denote to unexpected (and often undesirable) behaviours resulting from unpredicted interactions between some subsystems.

Sinha (2014), Carlson and Doyle (2002) suggest that evolving a product in order to improve its functionalities generally goes together with an increase in complexity, which represents potentially harmful and costly side effects. However, this does not mean that complexity must systematically be avoided. This suggests that designers face a *trade-off* between ‘increased functionality’ versus ‘harmful side effects and associated costs’: indeed, the value to be gained from a functional increased can be worth paying the cost of complexity. (Sinha, 2014 ; Carlson and Doyle, 2002).

Since increasing complexity appears central in product evolution, the next subsection is dedicated to the laws which appear to govern the evolution of complexity, as the product evolves.

2.2 Product complexity evolution laws

2.2.1 *A convergence process toward a simplified configuration*

According to some scholars, the evolution dynamic of a product can be seen as a phase of ‘complexification’ (in which functionalities are improved at the expense of simplicity) followed by a phase of ‘simplification’ (Salamatov, 1999), that is of convergence toward a simplified and ideal state (Altshuller, 1984). A parallel can be made with technology S-curves (Christensen, 1994) describing the evolution of a product toward a Dominant Design, the first flat phase, at which the product emerges corresponding to an emergence of functionalities and the second flat phase, after the inflexion point, corresponding to a stabilization, with only minor improvements (e.g. processes improvements…) and little change in the product itself. However, other research works suggest that the dynamics of product complexity and product evolution are not as simple as a ‘complexification’ phase followed by a ‘simplification’ phase.

2.2.2 *A continuous increase in complexity*

Carlson and Doyle (1999) describe a product dynamics characterized by a continuous complexification of technical systems. Their theory called ‘Highly Optimized Tolerance’ explains this trend. ‘Highly optimized’ denotes to systems that are highly performing. ‘Tolerances’ outline a high level of structuration / organization. HOT is defined in opposition with another complexity evolution dynamic theorized by NSCN (New Sciences of Complexity Networks). NSCN describe complex systems spontaneously evolving following self-organizing rules, which only required one parameter (the density of the systems elements) to be set. Carlson and Doyle (1999) stress that self-organization is suited for problems of *disorganized complexity*, involving an *infinite* number of *homogenous* elements, such as fractals for instance. But it is misleading to use these mechanisms to interpret or model the evolution of technical systems which fall into the problem category of *organized complexity*, involving a *large, but not infinite* number of *heterogeneous* interconnected elements. The elements of these very systems do not self-organize. Quite the opposite, a ‘designing force’ tunes several design parameters and rigorously arranges the elements of the system into a highly structured and hierarchized organization.

The evolution dynamics described by Carlson and Doyle is such that systems tend to become more and more robust. Indeed, technical systems are required to operate under increasingly large operating windows (e.g. an aircraft operating under extreme weathers). But as systems get more robust, they also become more sensitive to emergence phenomena (e.g. bugs…). They are designed to handle a larger spectrum of conditions. But the remaining and unpredictable conditions they are not designed for represent increasingly devastating perspectives if they occur. In order to counter emergence phenomena, the 'designing force' builds barriers aiming at preventing any "discussions" between the elements whose interaction represents risky emergence behaviours. Most of these barriers are not obviously detectable, they represent a form of hidden complexity. They keep expanding as the system gets more complex and robust. The concepts of product platforms, product lines, modularity, reuse, commonality (Kalligeros *et al*., 2006 ; Suh *et al*., 2004 ; Baldwin and Clark, 2006) propose design strategies aiming at helping designers implementing such barriers in order to keep complexity and costs under control.
These barriers can be interpreted as elements fulfilling new control functionalities in the system. However, HOT theory does not treat the scenario where new functionalities whose intended purpose would not be to prevent fragility but to add an additional characteristic to the system would emerge. The following subsection (2.3) reviews recent research works highlighting that the emergence of such new functionalities can be far from negligible within a technical system.

2.3 Product functional evolution law

Recent research works on product functional evolution reveal a steady increase in the emergence of new functionalities which affects consumption goods, such as the toothbrush, the hoover (El Qaoumi, 2016). These works identify a pattern of growth in the number of new functionalities that corresponds to a permanent transformation, involving not rare nor random, but frequent functional disruptions: such patterns of growth are characterized as regimes of functional expansion (El Qaoumi, 2016). If one considers each function as one edge of a graphic matroid, different possible evolution scenarii of the matroid rank can be associated with different regimes of functional expansion (El Qaoumi, 2016 ; Le Masson *et al*., 2018). One of these regimes is called 'endogenous expansion' where endogenous means that the functional change does not result from exogenous / external events (e.g. market-pull or techno-push dynamics, regulatory requirements…) but from a dynamic of design that is internal to the product. Empirical tests reveal that most of the studied consumption goods (apart from the refrigerator) follow this regime of endogenous expansion (El Qaoumi, 2016) which accelerates from the 1990s (Le Masson *et al*., 2018). These findings contrast with Lancaster's (1966) theory according to which the evolution of goods results from the combinations and re-combinations of a given fixed set of characteristics. Here, functional transformation takes place within a space which is in permanent expansion.

2.4 Research questions

Subsections 2.2 and 2.3 highlight the existence of two large-scale phenomena ((i) an explosion in robustness and (ii) an explosion in the number of functionalities) occurring at product level. These seem promising to help characterize the laws governing development cost escalation.
To our best knowledge, there exist no study documenting and representing a possible expansion of product functional space in the aerospace industry, although a few reports and papers (GAO, 2015 ; Dabkowski and Valerdi, 2016) attribute cost increase to the introduction of 'new system capabilities' (i.e. new functionalities), in retrospective studies of projects affected with cost overruns). One can note that most research works associating cost escalation phenomena with an increase in complexity resulting from functional improvements do not specify whether these very functional improvements regard existing functionalities or newly-introduced ones.
This leads to our first research question: *Are the products developed in the aerospace industry subject to a phenomenon of functional expansion, governed by an endogenous evolution law? (RQ1).*
If the answer to RQ1 is affirmative, our second research question is: *How can we model, and hence predict the cost growth pattern stemming from a product change scenario whose implementation is carried out with specific design capabilities? (RQ2)*
Finally, our third research question is: *To what extent can the cost escalation phenomena occurring within the aviation industry be (re)interpreted by identifying the design strategy revealed by these trends?(RQ3)*

3 METHOD

This paper results from investigations carried out within one global commercial aircraft manufacturing company. Therefore, we address RQ1 by testing whether the functional evolution of commercial aircraft is subject to a phenomenon of functional expansion. And in our answer to RQ3, the cost growth patterns which will be tested also come from projects led in the development area of commercial aircraft.

3.1 Testing the presence of a phenomenon of functional expansion at aircraft level

For an Aircraft to be certified, it must be demonstrated that its design complies with the Airworthiness Requirements applying at different levels. At aircraft level, the applicable regulation is CS-25 (released by the European regulation Agency, EASA) and FAR-25 (released by the American agency, FAA).

The amendments affecting FAR-25 and CS-25 are particularly interesting for our research. Indeed, two main mechanisms trigger regulatory changes. On the one hand, a change in design can be triggered by a change in the airworthiness requirements, following the report of an unsafe situation (most of the time revealed by incidents / accidents). Conversely, new functionalities or new designs initiated by aircraft manufacturers trigger the enactment of new airworthiness requirements in CS-25 and FAR-25, in order to make the new design certifiable. Therefore, changes in certification requirements record the introduction of new or updated (e.g. reprioritized) intended purposes at aircraft level (i.e. new functionalities). For this reason, with one paragraph of CS-25 / FAR-25 used as a unit, we counted and summed, at the time of each Amendment: (i) the number of added paragraphs, (ii) modified paragraphs, (iii) deleted paragraphs (counted positively), in order to assess the magnitude of the changes affecting commercial aircraft functionalities.

3.2 Cost growth and design strategies associated with robustness explosion and functional expansion - modelling and simulation method

In order to associate robustness explosion and functional expansion with cost growth patterns, we introduce a simple functional cost model built on the following parameters and principles. Let us consider a system consisting of *n* interconnected functionalities $F_1,\ldots,F_n$. The different functionalities $F_1,\ldots,F_n$ are improved as time *t* increases. Let $U_{F_i}(t)$ be the cost required to develop the functionality F_i individually, as an independent element from the system, at time *t*. The functionality F_i is also connected to a percentage p_i of the *n-1* other functionalities. Let $I_{F_i}(t, p_i)$ be the cost related to the integration of F_i within the system. For the simplicity of the simulation, in what follows, $p_i = p, \forall i = 1\ldots n$ where *p* is a constant percentage which can be seen as the average level of connectedness of the system. Therefore, the total cost associated with the functionality F_i at time t is $C_{F_i}(t) = U_{F_i}(t) + I_{F_i}(t, p)$. And the total development cost of the system is

$$\sum_{1\le i\le n} C_{F_i}(t) = \sum_{1\le i\le n} [U_{F_i}(t) + I_{F_i}(t, p)] = U_{\text{total}}(t) + I_{\text{total}}(p,t)$$

As time *t* increases, some functionalities F_i are required to be upgraded. And the engineering department faces a first challenge that is the obsolescence of the required knowledge to individually develop one functionality: we will describe this challenge with the function $\gamma_{1,\mathrm{i}}(t)$ affecting the functionality F_i. However, for the simplicity of our simulation, $\gamma_{1,\mathrm{i}}(t) = \gamma_1(\mathrm{t}) \ \forall i = 1\ldots n$. Since our purpose will be to simulate the ‘minimum’ cost increase that can be expected from a product modification, we can consider that we chose $\gamma_1(t)$ such that $\gamma_1(t) = \min_{1\le i\le n} \gamma_{1,\mathrm{i}}(\mathrm{t}) \ \forall t$. Under these conditions, the evolution of the cost to develop F_i as an independent element can be modelled with the recurrent equation:

$$U_{F_i}(t) = \frac{\gamma_1(t)}{\delta_1(t)}. \quad U_{F_i}(t-1) \tag{1}$$

where $\delta_1(t)$ is a function representing the capacity of an engineering department to counter obsolescence, i.e. the capacity of en engineering department to update and extend its current knowledge regarding individual functionalities. It can be seen as a learning rate.
Besides, improving some individual functionalities in order to make them more robust is likely to generate undesirable interactions (*emergence phenomena*) between systems which must be managed by engineering departments. If we describe the magnitude of emergence phenomena with the function $\gamma_2(t)$, the evolution of integration costs can be modelled with the following equation:

$$I_{\text{total}}(t,p) = \frac{\gamma_2(t)}{\delta_2(t)}. \quad I_{\text{total}}(t-1,p) \tag{2}$$

where $\delta_2(t)$ describes the capacity of the engineering department to master emergence phenomena.
For k = {1,2}, the capacity of an engineering department to cope with the challenge of obsolescence or emergence depends on whether the ratio $\frac{\gamma_k(t)}{\delta_k(t)}$ is more or less than 1.

We now consider the introduction of set of *m* new functionalities $\{F_{n+1},\dots,F_{n+m}\}$ within the system. An engineering departments will have to both deal with the 'individual' development of the new functionalities and with the integration of the new functionalities within the existing system. We could use the extent to which the newly-introduced functionalities are more expensive than the average cost of the initially existing individual functionalities (which we call $U_{average}$) to characterize the engineering department's capacity to manage the individual development of new functionalities. However, the cost increase due to *m* new functionalities is likely to weigh less than the cost due to the new interactions can amount up to $\frac{m*(m+n-1)}{2}$. Therefore, since we want to simulate the 'minimum' cost increase that can be expected when modifying the product, we will use the extent to which the number of new interactions is 'contained' to characterize the engineering department's capability to manage the introduction of new functionalities. To that end, we introduce the parameter $r_3(t)$, a percentage which is such that number of new interactions is $r_3(t).\frac{m*(m+n-1)}{2}$. In our simulation, $r_3(t)$ can take three values: low, medium or high percentage.
In subpart 4.2, we model the cost evolution patterns characterizing different scenarii depending on (i) the magnitude of *obsolescence* phenomena $\gamma_1(t)$ and the *learning* capability of the engineering department ($\delta_1(t)$), (ii) the magnitude of *emergence* phenomena $\gamma_2(t)$ the capability of the engineering department to control it it ($\delta_2(t)$) (iii) the introduction of new functionalities and $r_3(t)$, the capability to integrate them.

3.3 Test of our model - case study method

In order to address RQ3, we study growth cases observed during the development of commercial aircraft and we attempt to identify the scenario of our model which they correspond to.

4 RESULTS

4.1 A phenomenon of functional expansion affecting the development of commercial aircraft

We counted the accumulation number of paragraph modifications, additions and deletions in CS-25 and FAR-25 with time: the results are given by the two increasing curves below.

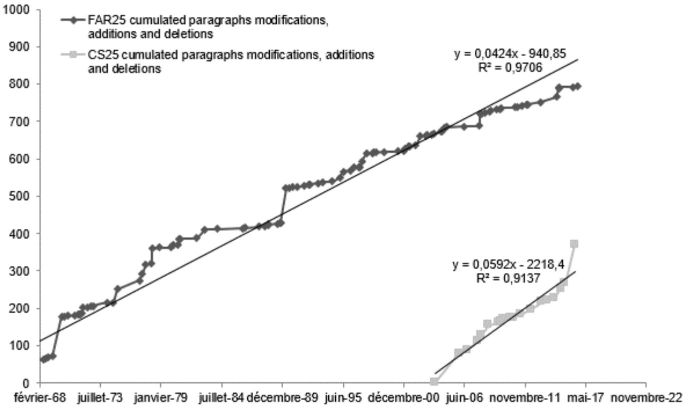


Figure 2. A steady growth in the number of regulatory changes affecting CS-25 and FAR-25

Focusing on the data collected on FAR-25 (because they feature a longer time span), we tested whether these trends correspond to a phenomenon of functional expansion. The endogenous regimes of functional expansion (mentioned in the literature review - 2.4) can be identified by representing the evolution of $r^2 - r_0^2$ where r is the rank of a matroid and by identifying whether or not the data fit with a linear regression. If they do, this means that we are in the face of an endogenous regime of functional expansion (Le Masson *et al.*, 2019). An horizontal line corresponds to no expansion. The larger the slope of the regression line, the larger the magnitude of the endogenous functional expansion, and the greater the innovative design effort that is required on the part of the engineering department.

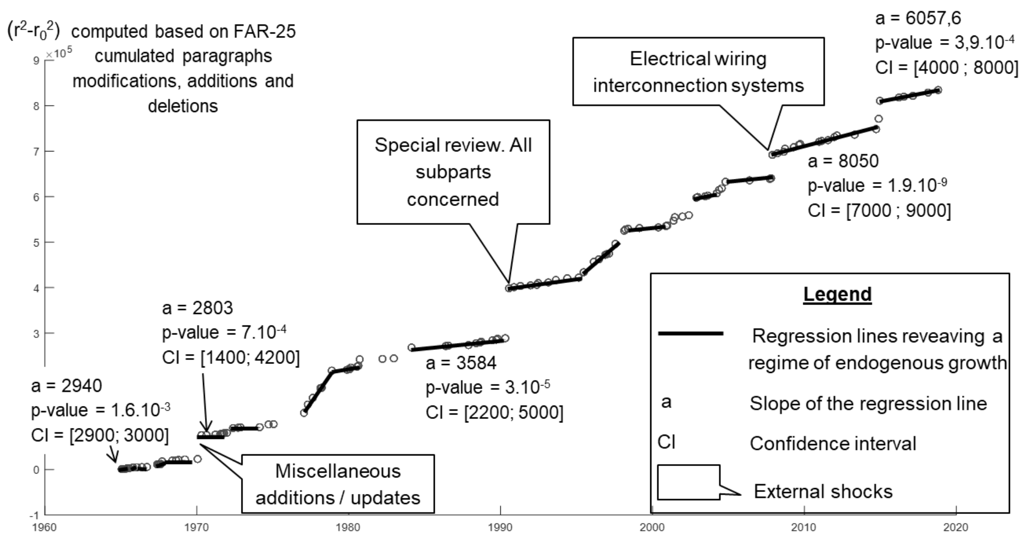


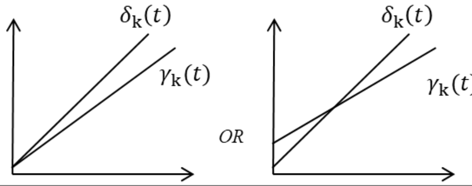
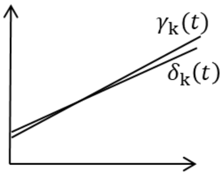
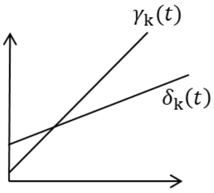
Figure 3. Identification of a slow endogenous regime regularly disturbed by external shocks

The results feature a regime of slow endogenous functional expansion regularly interrupted / disturbed by external shocks. The slope of the individual regression lines seems to increase with time, but verifying that the expansion regime indeed accelerates would require further statistical tests. Here, the results enable to answer *RQ1*: the development of commercial aircraft occur within an expanding functional space, implying an instable context involving both the frequent engineering improvements and frequent functional disruptions.

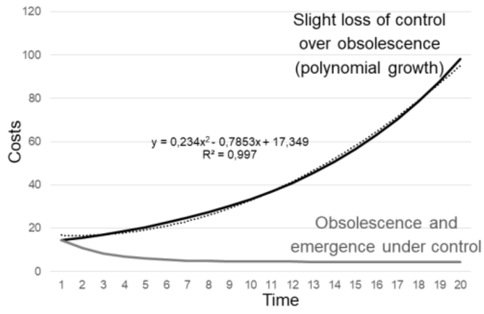
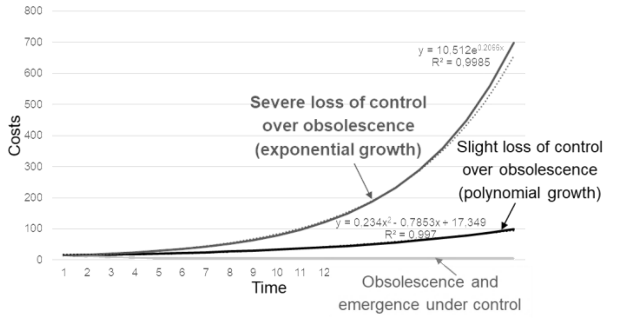
4.2 Cost growth patterns associated with the management of robustness improvement and functional expansion

4.2.1 Absence of new functionalities

In our simulation, we will model $\gamma_1(t)$, $\delta_1(t), \gamma_2(t), \delta_2(t)$ as linear functions. For k = {1,2}, the relative positions of the lines representing $\gamma_k(t)$ and $\delta_k(t)$ represents the capacity of an engineering department to master the challenge (emergence or obsolescence). For k = {1,2}, the capacity of an engineering department to cope with the problem of obsolescence or emergence depends on whether the ratio $\frac{\gamma_k(t)}{\delta_k(t)}$ is more or less than 1. The three different scenarii (S1., S2 and S3) can be distinguished:

	**S1. Design situation under control** If these are the patterns for k = 1 AND k = 2, this family of lines relative positions leads to decreasing costs
	**S2. Slight loss of control** The obsolescence (resp. emergence) phenomena are increasing slightly more faster than the engineering capacity to deal with them
	**S3. Severe loss of control** The obsolescence (resp. emergence) phenomena are increasing much faster than the engineering capacity to deal with them

Note: in the figures that follow, the horizontal axis features time, the vertical axis features costs. As time increases, existing functionalities are regularly upgraded.

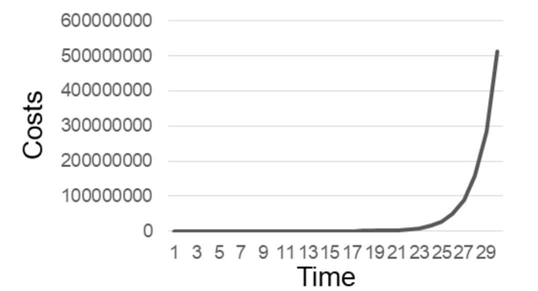
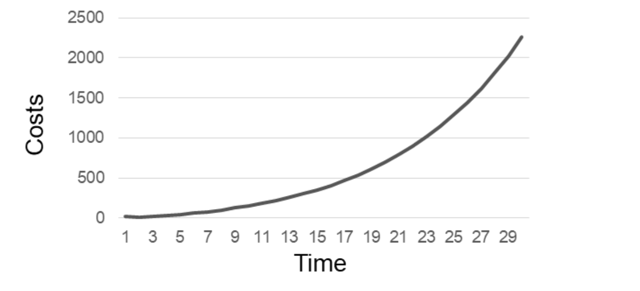
Loss of control over obsolescence only (simulation from S1 to S3)	
	
A slight loss of control over obsolescence (i.e. learning increases slower than obsolescence) results in a polynomial cost increase.	If the loss of control becomes too severing, the cost growth becomes exponential (emergence is still under control here). The two inferior curves are the same as the figure of the left

The simulation of a sole loss of control over emergence provides the same kind of results: as the loss of control becomes more dramatic, the trend shifts from polynomial to exponential. Unsurprisingly, given that emergence affects the interactions, which are more numerous than the functionalities, the threshold of the exponential growth is reached earlier with emergence phenomena. A loss of control alone can give rise to a superexponential growth. And unsurprisingly, combining both losses of control amplifies the cost growth phenomenon.

4.2.2 Introduction of new functionalities

We started by simulating a scenario in which the three aspects (obsolescence, emergence and introduction of new functionalities) were all out of control: we used a slight loss of control (S2.) for obsolescence and emergence. And we set . r_3 corresponding to the percentage of the new $\frac{m*(m+n-1)}{2}$ possible new functionalities that have to be dealt with by designers is “high” (80%)). Such a scenario results in a super-exponential cost growth.

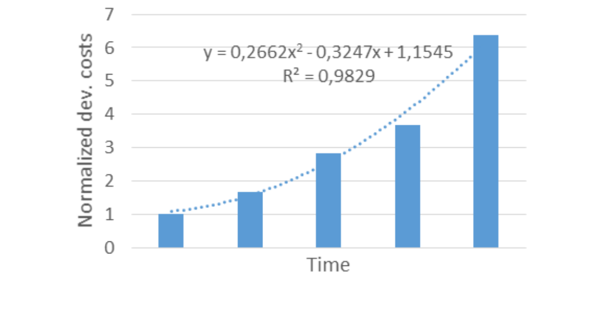
Then, we attempted to identify the levers which could render the cost growth polynomial. The results are the following:

	
Regaining control over obsolescence, even unrealistically, with a $\frac{\gamma_1(t)}{\delta_1(t)}$ ratio extremely low, does not improve (at all) the superexponential trend	Significantly (unrealistically, with a $\frac{\gamma_2(t)}{\delta_2(t)}$ ratio extremely low) regaining control over emergence turns the previous super-exponential growth into a polynomial growth again

Or a last means to find back a polynomial cost growth is to set all control parameters at a reasonably good level of control.

4.3 Test on empirically observed phenomena

As a first test, we applied our model of the development cost trend followed by five successive programs launched by one aircraft manufacturer, over a period of 25 years. In order to eliminate from the comparison the possible impact resulting from economic factors (inflation, cost of material…), the costs were discounted so that they all reflect the same economic condition.

	We observe a polynomial cost growth (n^2) which reveals: - either a reasonably good control of the three design aspects that are: functionalities individual upgrade, integration, and functional expansion - or an "uncontrolled" introduction of new functionalities compensated by extremely controlled integration capabilities

5 CONCLUSION

The considerable extent of the cost escalation trends presented in the introduction seems to highlight at first sight an alarming phenomenon, symptomatic of engineering departments having lost control over product development. By incorporating in a model three phenomena occurring at product level (1-obsolescence phenomena ; 2-emergence phenomena ; 3- new functionalities) and three associated control parameters (controlled by designers), our model suggests that genuine 'out of control' situations should be characterized by exponential or even superexponential cost growth patterns. Therefore, our findings relativize the alarming character of the observed cost escalation. Put differently, given the dramatic extent demonstrated by products increase in robustness and functional expansion, the observed cost growth appear relatively well-contained. This suggests that engineering departments would own a 'hidden capability' which actually addresses very efficiently the challenges raised by transformations at product level, in particular phenomena of functional expansion. The different patterns of growth associated with the different scenarii could provide a firm with a diagnosis of its capacity not only to manage costs, but more importantly to manage robustness and functional expansion. However, these results are still at a nascent stage. We need to test the correctness of the diagnosis on additional cases and to refine the model in order to identify other possible cost patterns.

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Henri Fayol et la théorie du chef d'entreprise

Une nouvelle figure de l'autorité au tournant du XXe siècle

Armand HATCHUEL

Si Fayol cherche à construire une nouvelle théorie du chef d'entreprise, c'est que les ruptures industrielles de son temps appelaient pour lui une révision complète des modèles classiques de l'autorité. En rapprochant la carrière scientifique et particulièrement innovante de Fayol et son traité *Administration industrielle et générale*, ce chapitre met en lumière la singularité de l'autorité du chef d'entreprise, qui a en charge la construction d'un corps social capable de faire advenir de nouveaux futurs par la recherche scientifique mais aussi d'affronter l'inconnu qu'il provoque par là-même[1].

1. Pourquoi relire ou lire Fayol, un siècle après ?

Il y a un siècle, paraissait la première publication du traité d'*Administration industrielle et générale*[2]. Henri Fayol est ensuite rentré dans l'histoire comme le père d'une doctrine administrative fondée sur des principes rigides et universels, rationaliste et qui fut souvent réduite à quelques formules dans la littérature[3]. Récemment, plusieurs réévaluations de son œuvre ont été engagées[4]. Elles montrent que Fayol avait prévu certaines tendances du management au XXe

1 Ce chapitre correspond à l'article paru sous le même titre dans la revue *Entreprise et Histoire*, n°83, vol. 2, juin 2016, p. 108-120 ; son contenu avait été présenté en tant que key-note speech au moment du Colloque Henri Fayol, organisé à l'École de mines de Saint-Étienne au printemps 2016. Nous remercions vivement Patrick Fridenson pour avoir autorisé son insertion dans le présent ouvrage.

2 H. FAYOL, « Administration industrielle et générale », *Bulletin de la Société de l'industrie minérale*, 5e série, Vol. 10, n° 3, 1916, p. 5-162.

3 H. MINTZBERG, « The manager's job: folklore and fact », *Harvard Business Review,* Vol. 53, n° 4, July-August 1975, p. 49-61. Republié dans le n° de March-April 1990 avec un commentaire rétrospectif.

4 P. CHAMBERS, « Europe's greatest management pioneer », *International management,* Vol. 29, June 1974, p. 48 51 ; J.-L. PEAUCELLE, « Fayol méconnu et toujours original », *Entreprises et Histoire,* n° 34, décembre 2003, p. 5-7 ; J.-L. PEAUCELLE *et alii, Henri Fayol: inventeur des outils de gestion: textes originaux et recherches actuelles*, Paris, Economica, 2003; D. LAMOND, « A matter of style: reconciling Henri and Henry », *Management Decision*, Vol. 42, n° 2, 2004, p. 330-356; M. G. PRYOR et S. TANEJA, « Henri Fayol, practitioner and theoretician–revered and reviled », *Journal of Management History*, Vol. 16, n° 4, 2010, p. 489-503.

siècle[5]. Elles soulignent son rôle précurseur dans l'invention des «outils de gestion[6]». Elles examinent les relations entre ses recommandations et son action[7]. Mais dans l'ensemble, ces travaux ne remettent pas en cause la lecture traditionnelle du traité, telle qu'elle a été fixée, avant la Seconde Guerre mondiale, notamment aux États-Unis[8].

Dans cet article, nous présentons les éléments d'un réexamen critique du traité. Trois éclairages convergents autorisent à lire Fayol autrement : i) les figures traditionnelles du chef dont il a voulu s'écarter ; ii) le nouveau contexte industriel et scientifique dans lequel il était plongé ; iii) les indications de Fayol lui-même affirmant explicitement dans un texte publié (à l'occasion de sa candidature à l'Académie des Sciences) mais peu étudié[9] qu'un message majeur de son traité était le nécessaire – et novateur – rapprochement de la science et l'industrie : «Et ce n'est pas la tâche la moins difficile du chef d'entreprise que de conjuguer les efforts des savants et des praticiens. Il y a de nombreux obstacles à surmonter : je l'ai montré dans mon ouvrage sur l'Administration industrielle et générale ; mais en même temps j'ai proclamé l'indispensable nécessité pour l'industriel d'organiser et de réussir la collaboration de la science avec le monde des affaires. Cette idée pleine de promesses et qui vient maintenant à l'honneur m'est chère depuis bien longtemps et je puis dire que, sur ce point, ma Société a donné l'exemple[10]». Comme l'avait souligné Yves Cohen[11], Fayol ne pense pas ses principes administratifs hors de tout contexte. Il voit sa doctrine comme une réponse aux nouveaux rapports entre science, industrie et travail qui s'installent à la fin du XIX[e] siècle, et notamment au constat qui oriente toute son œuvre : la nécessité d'un nouveau type d'autorité, celle du «chef d'entreprise» dont il s'efforce de décrire, dans son traité, les missions et les compétences.

Innovateur, Fayol voulait donc être lu à partir de son expérience singulière, où l'action du dirigeant, les travaux du savant et les audaces de l'innovateur ont été indissociables.

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5 M. J. FELLS, «Fayol stands the test of time», *Journal of Management History,* Vol. 6, n° 8, 2000, p. 345-360 ; D. A. WREN, «*Henri Fayol as strategist: a nineteenth century cor*porate turnaround», *Management Decision*, Vol. 39, n° 6, 2001, p. 475 – 487 ; L. D. PARKER et P. A. RITSON, «Revisiting Fayol: Anticipating Contemporary Management», *British Journal of Management,* Vol. 16, n° 3, 2005, p. 175-194 ; J. W. YOO, D. J. LEMAK et Y. CHOI, «Principles of management and competitive strategies: using Fayol to implement Porter», *Journal of Management History*, Vol. 12, n° 4, 2006, p. 352-368.

6 J.-L. PEAUCELLE et alii, *Op. cit.*

7 D. REID, «Genèse du fayolisme», *Sociologie du Travail,* janvier 1986, p. 75-93 ; D. REID, «Fayol : excès d'honneur ou d'indignité ?», *Revue Française de Gestion*, septembre-octobre 1988, p. 151-159.

8 L. URWICK, «Foreword», in H. FAYOL, *General and Industrial Managemen*t, Londres, Pitman, 1949. D. A. WREN, *Art. cit.* ; D. A. WREN, A. G. BEDEIAN ET J. D. BREEZE, «The foundations of Henri Fayol's administrative theory», Management Decision, Vol. 40, n° 9, 2002, p. 906-918.

9 H. FAYOL, *Notice sur les travaux scientifiques et techniques de M. Henri Fayol*, Paris, Gauthier-Villars et Cie Editeurs, 1918. En ligne sur le site de la Bibliothèque Nationale de France : http://gallica.bnf.fr/ark:/12148/bpt6k904289.r=notice+fayol.langFR

10 *Ibid.* La Notice sur les travaux scientifiques et techniques de M. Henri Fayol n'a jamais été traduite en anglais et son contenu n'a jamais été discuté, en relation avec le traité, à notre connaissance. Sur l'échec de la candidature de Fayol à l'Académie : O. HENRY, «Un entrepreneur de réforme de l'État : Henri Fayol (1841-1925)», *Actes de la recherche en sciences sociales,* n° 193, juin 2012, p. 38-55.

11 Y. COHEN, «Fayol, un instituteur de l'ordre industriel», *Entreprises et Histoire,* n° 34, décembre 2003, p. 29-67.

Quand il publie son traité, il est au soir d'une carrière exceptionnelle. Il a développé un groupe métallurgique et minier, dont il devient directeur général en 1888. Surtout, ce développement a été favorisé par des découvertes scientifiques et des innovations techniques parfois majeures[12]. La plus célèbre de ces découvertes est certainement celle de l'Invar, un acier au nickel qui ne se dilate pas. Elle est obtenue en 1896, grâce à l'aide que Fayol accorde à un physicien suisse du Bureau international des poids et mesures de Genève, Charles-Édouard Guillaume, qui collaborera avec ses usines durant plusieurs décennies. Cette découverte vaudra à Guillaume le prix Nobel de physique en 1920[13]. Elle apporte à Fayol, et bien après lui, une moisson exceptionnelle de nouveaux marchés[14]. Auparavant, Fayol avait bousculé la géologie de son temps en élaborant la «théorie des deltas[15]», à laquelle il attribue l'exploitation particulièrement efficace de sa mine de Commentry. Enfin, en 1911, il nomme à la tête du laboratoire d'Imphy Pierre Chevenard, et lui confie une mission aussi ambitieuse qu'originale lorsqu'on la compare à l'activité des nouveaux laboratoires industriels qui naissent dans cette période[16]. Pierre Chevenard et son laboratoire incarneront pendant plusieurs décennies la nouvelle métallurgie de précision[17] (voir les articles de F. Duffaut et de P. Le Masson et B. Weil dans le numéro de la revue *Entreprises et histoire* consacré au tournant fayolien[18]).

1.1. Le chef fayolien : une figure difficile à penser, des concepts complexes

Au terme d'un tel parcours, Fayol ne se propose pas d'exalter le «caractère» du vrai chef ou l'art de se faire obéir. Au contraire, il assigne au nouveau chef d'entreprise des missions aussi complexes que surprenantes pour l'époque : celle de susciter un «perfectionnement» permanent et indéfini de toutes les activités de l'entreprise, celle d'agir comme un chef politique attentif à «constituer le corps social» de l'entreprise.

Étonnamment, la difficulté théorique d'un tel projet, dans les référents doctrinaux de la fin du XIX^e^ siècle, n'a pas été assez soulignée.

12 H. FAYOL, *Notice, Op. cit.,* en fournit une recension complète.

13 R. W. CAHN, «An unusual Nobel prize», *Notes and Records of the Royal Society*, Vol. 59, n° 2, 2005, p. 145-153.

14 E. LAMBRET et G. SAINDRENAN, «The discovery of Invar and the metallurgical works of Charles-Edouard Guillaume», in J. WITTENAUER (dir), *The invar effect : A centennial symposium, Warrendale*, PA, The Minerals, Metals and Materials Society, 1996, p. 39-47.

15 B. BEAUDOIN, «Henri Fayol, géologue perspicace et novateur ?», in J.-L. PEAUCELLE *et alii, Op. cit.,* p. 47-67.

16 P. CHEVENARD, «L'installation et l'organisation d'un laboratoire sidérurgique moderne», *Mémoires de la Société des ingénieurs civils de France*, Vol. 86, septembre- octobre 1933, p. 3-52.

17 P. CHEVENARD, «La recherche scientifique dans l'industrie française. Réflexions et souvenirs», *Mémoires de la Société des ingénieurs civils de France*, Vol. 104, janvier-avril 1951. L'original de ce texte est déposé aux Archives départementales de la Nièvre, 95 J 199.

18 F. DUFFAUT, «Pierre Chevenard ou la recherche au cœur de l'entreprise moderne», *Entreprises et histoir*e, n°83, juin, 2016, p. 64 à 78 et P. Le MASSON & B. WEIL, «Fayol, Guillaume et Chevenard, la science, l'industrie et l'exploration de l'inconnu : logique et gouvernance d'une recherche cognitive», *Entreprises et histoire,* n° 83, juin 2016, p. 79 à 107.

Elle explique pourtant la complexité, l'abstraction, voire l'étrangeté des concepts fayoliens[19]. Car, bien qu'il s'adresse à ses pairs, Fayol expose sa doctrine dans une langue qui n'est en rien celle des affaires. Plus surprenant, il ne fait aucune référence à l'économie politique de son temps. Ses concepts principaux - «prévoyance», «programme d'action», état-major, «inconnu», perfectionnement, union du corps social - puisent sans conteste dans la philosophie politique et la théorie sociale du XVIII^e^ et du XIX^e^ siècle, et situent l'ambition élevée du traité : une nouvelle pensée de la société et du gouvernement.

1.2. Retrouver une lecture rigoureuse du traité

Une telle ambition théorique et sous la plume… d'un chef d'industrie ! Le fait aurait dû inviter à une exégèse prudente. Mais il est vrai que la complexité du texte de Fayol disparaît dans les traductions anglaises effectuées par J. A. Coubrough[20] et C. Storrs[21,] et publiées après sa mort. Elle échappe ainsi à son lectorat international[22]. Pour relire Fayol, il faut donc s'en tenir au texte français et appréhender ses concepts les plus originaux à partir de la visée centrale qu'il indique lui-même : penser un chef adapté à un nouveau monde industriel où la recherche et la science modifient les missions de l'entreprise, ses modalités d'action et la structure des collectifs de travail.

À quoi se heurtait une telle visée ? Dans la première partie de cet article, nous reviendrons d'abord sur les figures du «chef» héritées du XIX^e^ siècle : le patron, l'administrateur et le gérant. Nous évoquerons ensuite le monde industriel fayolien en insistant sur la nouvelle «fonction technique», faite de bureaux d'études et de laboratoires, qui s'impose dans les industries de pointe et rend obsolètes les anciennes formes de l'autorité.

Dans la seconde partie, nous présenterons, sous ce nouvel éclairage, le système de concepts fayoliens. Il témoigne d'une complexité et d'une cohérence peu soulignées jusqu'ici. On peut dire de la mission du chef d'entreprise fayolien qu'elle est à la fois créatrice et politique. La mission créatrice, soutenue par l'effort de recherche, était en germe à son époque à travers la littérature internationale[23] mais Fayol lui donne une signification inattendue. La mission politique est plus surprenante. Fayol décrit un chef d'entreprise qui doit «constituer le corps social de l'entreprise»; qui est attaché aussi bien à l'intérêt général qu'à l'intérêt privé, les deux intérêts se rejoignant dans sa conception du «perfectionnement». Enfin, contrastant avec les doctrines contemporaines, le traité n'évoque jamais le profit des actionnaires comme

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19 Une comparaison avec le langage simple et technique de Frederick W. Taylor est ici éclairante.

20 H. FAYOL, *Industrial and General Administration,* J.A. Coubrough, Londres, Sir Isaac Pitman & Sons, 1930.

21 H. FAYOL, *General and Industrial Management,* C. Storrs, London, Sir Isaac Pitman & Sons, 1949.

22 Pour un tableau des concepts fayoliens dont la complexité disparaît dans les traductions cf. D. A. WREN, «The influence of Henri Fayol on management theory and education in North America», Entreprises et Histoire, n° 34, décembre 2003, p. 98-107 et A. HATCHUEL et B. SEGRESTIN, «Fayol, théoricien de l'entreprise innovante», in M. BERTILORENZI, J.-P. PASSAQUI, A.-F. GARÇON (dir.), *Entre technique et gestion. Les ingénieurs civils des mines et l'industrialisation de la France et d'ailleurs, XIX^e^-XX^e^ siècles*, Paris, Presses des Mines, 2016.

23 Elle était aussi centrale chez Taylor, même si l'ingénieur américain limite son approche à la direction des usines. Voir aussi P. Le MASSON & B. WEIL, *Art. cit.*

seule finalité du dirigeant. Or, un siècle après la parution du traité, avec l'installation d'un capitalisme mondialisé et financiarisé, on assiste à une crise – ou tout au moins, à un brouillage – de la figure du chef d'entreprise[24]. Retrouver les fondements du tournant fayolien pourrait contribuer à la refondation actuellement débattue de l'entreprise et de ses chefs.

2. Figures de l'autorité et mutations industrielles vers 1890

Au XIXe siècle, trois figures du «chef» semblent suffire pour la conduite des affaires privées ou des charges publiques[25]: le patron-entrepreneur, l'administrateur et le gérant.

2.1. Les figures du chef avant Fayol: le patron, l'administrateur et le gérant

Le patron-entrepreneur est la plus répandue. Héritier du marchand et du maître-artisan, il tirait son pouvoir de la maîtrise d'un métier. Mais avec l'abolition des corporations, son statut d'entrepreneur-propriétaire et d'employeur s'est substitué à la légitimité du métier et encadre juridiquement son action. Les doctrines du «bon patron» ne manquent pas mais elles concernent le plus souvent sa responsabilité de «marchand»: comptabilité, tenue des stocks, qualité de la production. À la fin du XIXe siècle, on insiste sur le respect du code naissant du travail, qui enjoint de payer à temps ses ouvriers, de bien les traiter, de ne pas les humilier… Avec les luttes sociales, la question de la représentation syndicale et celle de la grève détermineront une relation patron-ouvrier forgée dans la conflictualité et normée par le droit.

La figure de l'administrateur remonte à l'antiquité et renvoie au détenteur d'une charge publique. Des travaux récents ont montré que cette figure se construit à l'époque romaine, avec l'invention d'un modèle de la «bonne gestion» qui diffuse avec l'Empire[26]. Après la Renaissance, on retrouve cet héritage dans les traités du «bon administrateur». Nommé par le Roi, la République ou la Cité, l'administrateur ne crée pas la mission qui lui est confiée et doit rapporter à ses mandants sur le contenu et les effets de son action. Cette reddition des comptes à un pouvoir supérieur marque une différence majeure avec le patron-entrepreneur qui ne rapporte qu'à lui-même.

En outre, l'administrateur doit incarner les valeurs de l'autorité qu'il représente. On attend de lui le souci du bien public et de l'intérêt général aussi bien qu'un comportement intègre, honnête, et juste. La figure de l'administrateur est donc indissociable d'un cadre politique et de règles qu'il doit respecter et faire respecter. *In fine*, pèse sur lui une obligation: «celle de faire adhérer au souverain qui lui a donné sa mission[27]».

24 B. SEGRESTIN et A. HATCHUEL, *Refonder l'entreprise,* Paris, Le Seuil, 2012.

25 Non militaires.

26 M. CRÉTÉ, «La «gestion» à l'époque romaine: naissance d'une nouvelle catégorie de l'action collective», *Entreprises et histoire*, vol. 90, no. 1, 2018, pp. 161-177.

27 A. GUERARD DE ROUILLY, *Principes généraux d'administration, ou Essai sur les devoirs et les qualités indispensables d'un bon administrateur*, Paris, Favre, 1815, 251 p.

Quant au gérant de société ou d'affaires, il connaît un développement important avec la société anonyme. Ce n'est pas nécessairement un patron de métier, mais il dispose de toutes les prérogatives du patron. Il peut n'être pas lui-même un entrepreneur, ni même un propriétaire[28]. Il représente la société comme personne morale et peut contracter en son nom les engagements qu'il juge bons.

On peut voir le gérant comme un administrateur privé, qui doit rendre des comptes aux associés ou aux actionnaires, mais sans les repères qui définissaient la « bonne gestion » pour les administrateurs publics. Il lui faut avant tout conduire la société dans « l'intérêt » des associés. Enfin, si le droit lui accorde les pouvoirs les plus étendus, il ne précise en rien les compétences qui lui sont nécessaires et le contenu de son action, à l'exception des règles formelles liées à la société (comptes, assemblées, etc.). Le rôle du gérant a souvent fait l'objet de nombreux débats et litiges et on dispose de témoignages devant les tribunaux montrant l'ambiguïté de ses relations avec les commanditaires[29]. Lorsque, en 1860, Fayol débute sa carrière d'ingénieur, ces trois figures du chef semblaient universelles mais le nouveau monde industriel qui se construit bouscule leurs fondements en introduisant de nouvelles missions et de nouvelles compétences.

2.2. Après 1860, une nouvelle fonction technique

Les transformations de la production dont Fayol a été le témoin et l'acteur sont multiples mais trois d'entre elles ont un écho direct dans le traité.

Les bureaux d'études et la recherche industrielle

Le machinisme du XIX^{e} siècle se distingue d'abord par l'invention de nouvelles machines énergétiques (machines à vapeur, moteurs thermiques, moteurs électriques…) dont l'usage est « générique[30] », c'est-à-dire qu'il peut intéresser, et modifier, tous les métiers.

Ce machinisme connaît aussi un rythme de régénération sans précédent qui est à la fois la cause et la conséquence d'un développement inédit du travail de conception. À côté des usines, le bureau d'études devient le nouvel organe de la « fonction technique ». Entreprise indépendante ou service interne, il concentre les nouveaux ingénieurs et techniciens dans des collectifs inédits[31].

Ces bureaux d'études sont aussi le maillon entre l'usine et le laboratoire de recherche si important pour Fayol, qui entre aussi dans l'univers industriel à la même époque[32]. Ce

28 Tout au plus lui demande-t-on d'être un associé symbolique.

29 G. MADOL, *Compte rendu par un gérant à ses commanditaires,* Paris, Le Normant, 1840, 61 p.

30 O. KOKSHAGINA, *Risk management in double unknown : Theory, model and organization for the design of generic technologies*, thèse de doctorat de sciences de gestion, École des Mines ParisTech, 2014.

31 Cf. G. GALVEZ-BEHAR, « Les bureaux d'études », *Entreprises et Histoire*, n° 58, avril 2010.

32 P. LE MASSON et B. WEIL, « Aux sources de la R&D : genèse des théories de la conception réglée en Allemagne (1840-1960) », *Entreprises et Histoire,* n° 58, avril 2010, p. 11-50 ; P. LE MASSON et B. WEIL, « La conception innovante comme mode d'extension et de régénération de

sont les bureaux d'études (de la construction navale, de l'horlogerie, de l'automobile…) qui inventent de nouveaux usages et demandent des nouveaux alliages au laboratoire de Fayol. À l'inverse, ce sont eux qui expérimenteront les découvertes surprenantes de ce même laboratoire. À travers ces nouveaux organes, c'est un nouveau régime de savoir et d'action qui caractérise l'activité productive et qui rend l'avenir imprédictible.

L'administration problématique de la nouvelle «fonction technique»: l'activité des bureaux d'études et des laboratoires de recherche posait de nouveaux problèmes de direction.

Qui allait gouverner, et comment, ces nouvelles équipes? D'ailleurs étaient-elles gouvernables? Ne fallait-il pas simplement acheter leurs services et leurs conseils, comme on l'avait toujours fait avec les architectes? Les toutes premières compagnies anglaises de chemins de fer avaient d'ailleurs commandé la conception des locomotives à des ingénieurs externes comme les Stephenson. Il reste que dans beaucoup d'industries, la création de bureaux d'études internes et de laboratoires de recherche propres s'imposa, posant la question du type d'administration adaptée à des cols blancs chargés de construire l'avenir des firmes. Dans un ouvrage de 1907, Julien Dalemont décrit les services de la firme suisse Brown-Boveri et la multiplicité des activités administratives liées à la fonction technique. Il nous apprend aussi que ces activités avaient été finalement retirées à la fonction technique pour «relever désormais du Conseil [d'administration][33]». Le développement des fonctions techniques d'études et de recherche provoquait donc une rediscussion et une extension importante et inédite des activités du chef d'entreprise, ainsi que des fonctions commerciales.

Une représentation nouvelle du travail d'exécution

La fonction technique fixe la nature des produits à fabriquer et les conditions de leur fabrication. Elle peut aussi prescrire avec une grande précision le détail du travail ouvrier. Frederick Taylor est le premier à penser cette évolution en inventant une «fonction méthodes» qui réplique le bureau d'études au niveau du travail d'atelier. De plus en plus conçu *ex ante* par des bureaux d'études et de méthodes, le travail ouvrier est donc contraint de s'intégrer dans un collectif de production et de suivre des règles imposées par l'entreprise. Cette évolution érode les anciens métiers dotés d'une autonomie traditionnelle dans leurs savoirs et leurs outils. L'ouvrier dépendra de plus en plus de la fonction technique qui fixe les conditions d'exercice de son activité. En réaction, et à la suite des grandes luttes sociales, l'État organisera la protection des personnels en transférant par exemple au chef d'entreprise la responsabilité en matière d'accidents du travail (loi de 1898), en raison même de son autorité sur la nouvelle fonction technique.

L'ensemble de ces transformations rendait obsolètes les figures du patron, de l'administrateur et du gérant. Il revint à Fayol de prendre conscience de ce vide doctrinal et de proposer une nouvelle «doctrine administrative». La notion évoque encore les anciens traités du «bon

la conception réglée: les expériences oubliées aux origines des Bureaux d'études», Entreprises et Histoire, n° 58, avril 2010, p. 51-73.

33 J. DALEMONT, *La construction des machines électriques*, Paris, Librairie polytechnique, 1907, 138 p.

administrateur[34] », mais on va voir que Fayol subvertit la signification classique de la fonction administrative.

3. Le modèle fayolien : la mission créative et politique du chef d'entreprise

3.1. La mission centrale : « le perfectionnement »

Indéniablement, le chef d'entreprise fayolien se distingue des anciennes figures du chef parce qu'il veut réussir la collaboration de la science avec le monde des affaires. Cette idée est explicitement énoncée dans la Notice sur les travaux scientifiques et techniques que Fayol publie en 1918[35] où il affirme qu'il s'agit d'un message important de son traité. Un tel objectif ancre Fayol dans son époque et limite l'universalité de son traité. Mais en quoi cette idée redéfinit-elle la mission du chef d'entreprise ?

L'appel à des expertises spéciales entrait dans le répertoire d'actions du patron, de l'administrateur ou du gérant. Mais Fayol ne fait pas de la collaboration entre la science et le monde des affaires une action opportuniste dépendant des compétences du marché. Il prend la science comme le moteur principal d'un projet plus général, celui du « perfectionnement » qu'il désigne comme une mission majeure du dirigeant. « Parmi ces obligations [celles du chef d'entreprise] l'une des plus importantes est la recherche des perfectionnements. On sait bien qu'une entreprise qui ne progresse pas est bientôt en retard sur ses rivales et qu'il faut, par conséquent, poursuivre sans cesse le progrès dans tous les domaines[36] ».

Ainsi Fayol accepte-t-il la concurrence, mais il en retient l'effet positif sur le progrès général. Or celui-ci exige que tout chef d'entreprise soit investi d'une mission de perfectionnement permanent, seul gage de la pérennité de l'entreprise. En outre, Fayol ne relie pas cette mission au mandat qu'il a reçu des actionnaires. Il en fait une responsabilité intrinsèque du nouveau chef d'entreprise, responsabilité qui découle de sa conception des rapports entre intérêt privé et intérêt général : en perfectionnant son entreprise par la science, le chef d'entreprise accomplit son devoir vis-à-vis de l'intérêt général et protège aussi les intérêts privés, comme un capitaine de bateau protège la sécurité de ses passagers au nom de sa mission professionnelle et de l'intérêt général.

En choisissant le terme de « perfectionnement », Fayol s'inscrit directement dans la lignée des philosophes des Lumières.

Depuis le XVIII^e^ siècle, le terme désigne, avec Condorcet, Comte et bien d'autres, la conquête des plus nobles idéaux de l'humanité et vaut pour toutes les sphères du progrès : connaissance, arts, morale. Beaucoup d'établissements d'enseignement ont, à l'époque de Fayol, un conseil dit de « perfectionnement ». Le chef d'entreprise fayolien situe donc son

34 A. GUERARD DE ROUILLY, *Principes généraux d'administration, ou Essai sur les devoirs et les qualités indispensables d'un bon administrateur*, Paris, Favre, 1815. En ligne sur le site de la Bibliothèque Nationale de France : http://gallica. bnf.fr/ark:/12148/bpt6k5713763t

35 H. FAYOL, *Notice, Op. cit.*

36 H. FAYOL, « Administration industrielle et générale », *Op. cit.*, p.78.

autorité et sa responsabilité au plus haut niveau politique possible : contribuer au progrès collectif.

3.2. Les moyens du perfectionnement : un art collectif du programme dans l'inconnu

Mais comment le chef d'entreprise peut-il obtenir ces perfectionnements ? À cet effet, Fayol décrit son action à l'aide d'une série de concepts tout à fait originaux.

L'état-major fayolien : de son expérience il retient d'abord que le chef d'entreprise ne peut obtenir les perfectionnements recherchés qu'en constituant autour de lui un état-major de spécialistes de toutes natures, à la fois internes et externes à l'entreprise. À cet état-major il adjoint un laboratoire de recherches doté des moyens nécessaires et auquel il assigne une mission de « grande envergure » (Chevenard). Pour réussir l'insertion de cet état-major et du laboratoire dans la vie quotidienne de l'entreprise, un dispositif d'action plus général est nécessaire. Pour le décrire Fayol développe quatre concepts aussi complexes qu'originaux : prévoyance, programme, inconnu et union du corps social. On comprend mieux leur logique d'ensemble en partant de la notion d'inconnu. L'inconnu, une conséquence inattendue du nouveau monde industriel : Fayol remarque que du fait même des progrès et des perfectionnements, le chef d'entreprise du XX^e^ siècle est confronté à un futur qu'il faut envisager comme présentant inévitablement une « part d'inconnu ». Certes, selon les cas, la part d'inconnu sera réduite ou majeure, mais tout contribue à l'augmenter, y compris la propre action du chef d'entreprise, notamment parce qu'il ne sait pas où vont le mener les recherches qu'il engage lui-même.

L'idée d'« inconnu » est différente de celle d'« incertitude » qui domine dans la littérature économique et Fayol n'utilise jamais cette notion. Fayol ne précise pas de définition de l'inconnu[37]. Mais on peut aisément remarquer que les résultats de la recherche industrielle sont « inconnus » et pas seulement « incertains », comme on pourrait le dire des bénéfices de l'année.

Dans ce second cas, le bénéfice peut prendre des valeurs variées, aléatoires et même non probabilisables, mais la notion de bénéfice restera inchangée. Alors que la recherche peut aboutir à changer la définition des notions, ou à la découverte d'objets inconnus comme ce fut le cas avec l'Invar. En pratique, la distinction entre inconnu et incertitude a d'importantes conséquences. Un dirigeant peut lutter contre certaines incertitudes connues même si elles sont non probabilisables. Mais face à l'inconnu, il doit choisir entre ne rien faire et s'engager lui-même dans la recherche. Il peut aussi préparer le corps social de l'entreprise à l'inconnu, par exemple en le formant à la démarche scientifique et en favorisant les initiatives.

Pour décrire l'instrument de direction qui doit s'adapter au niveau d'inconnu et mobiliser le corps social de l'entreprise, Fayol choisit, à nouveau, un terme surprenant : « le programme général d'action ». Et, selon l'ampleur de l'inconnu, ce programme peut prendre trois formes que l'on peut illustrer par des pratiques de Fayol :

37 Cette notion joue un rôle central dans la théorie contemporaine de la conception : P. LE MASSON, B. WEIL et A. HATCHUEL, *Théorie, méthodes et organisations de la conception,* Paris, Presses des Mines, 2014

- une liste d'actions et d'objectifs précis à atteindre lorsque «la part d'inconnu est réduite». Ce sont par exemple les tableaux de prévisions quantitatives qu'il donne en exemple dans son traité.
- une «directive» lorsque le dirigeant ne peut indiquer qu'une orientation, sans pouvoir en dire plus, mais celle-ci peut se révéler déterminante.

C'est le cas de la directive qu'il donne en 1911 à Pierre Chevenard lorsqu'il le nomme directeur du laboratoire d'Imphy[38].

- une «aventure» lorsque l'inconnu est majeur. On retrouve ici son partenariat avec Guillaume, qu'il a soutenu très tôt sans que rien ne puisse prédire ce qui allait en résulter.

Programme, commandement et corps social: Le terme de «programme» renvoie aussi au langage de l'action politique. Fayol n'utilise jamais les termes de «plan» ou de «plan prévisionnel». Avec le terme de «programme», Fayol confère au chef d'entreprise une stature volontariste et visionnaire. Un programme n'est pas une réponse passive aux événements, il exprime des convictions et un futur souhaité que l'on devra activement préparer. «Programme» évoque peu la relation entre commandement et subordonnés, il appelle plutôt l'adhésion de ceux à qui il est proposé.

D'ailleurs Fayol définit le commandement par une image inédite, «commander, c'est-à-dire faire fonctionner le personnel».

«Fonctionner» se dit en général d'une machine, l'image pourrait donc passer pour méprisante et inhumaine. Mais Fayol évite ainsi le lieu commun: «commander, c'est se faire obéir». «Fonctionner» ouvre un large espace d'associations qui invitent à rechercher un consentement préparé, et toujours conditionnel, du personnel. En effet, une machine ne fonctionne que si on en a pris soin, si on respecte des règles précises de marche, si on réagit aux signes d'alerte, etc. Tous les passages du traité relatifs au personnel confirment que Fayol explore une conception du commandement qui ne fait pas de l'obéissance le seul but recherché.

Fayol sait qu'il a besoin d'un assentiment du personnel pour maintenir ses objectifs de «perfectionnements»: il lui faut un personnel compétent, préparé et adapté à la variété nécessaire des programmes à lancer. En retour, un tel personnel attend que le chef d'entreprise défende avant tout la pérennité de l'entreprise, ce que Fayol appelle être un chef «prévoyant».

3.3. La prévoyance selon Fayol: une rationalité responsable face à l'inconnu

Fayol vit dans un monde marchand et concurrentiel, mais, en tant que chef d'entreprise, la rationalité du marchand ne lui suffit plus. Elle ne permet ni de penser le futur comme un savant, ni de construire des programmes, ni de faire fonctionner le personnel. On peut donc lire le traité comme l'exposé implicite d'une forme nouvelle de rationalité inséparable d'une théorie de la responsabilité.

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38 P. Le MASSON & B. WEIL, *Art. cit.*

Cette nouvelle rationalité naît d'un double constat : i) une part importante du futur est imprédictible ; ii) une part du futur ne peut exister que si elle est provoquée par l'action humaine, et notamment la recherche scientifique.

Il en découle que le dirigeant fayolien n'a pas pour seul but de réduire l'incertitude. Lui importe, autant, de régénérer le connu, donc de faire advenir de nouveaux futurs. Pour exprimer une idée aussi nouvelle et aussi complexe, Fayol détourne à nouveau la langue habituelle et joue avec les multiples significations de mots connus.

« Prévoyance » est celui qu'il retient pour désigner cette nouvelle façon de penser les rapports entre l'entreprise et le futur. Avec ce choix, Fayol n'hésite pas à s'éloigner du sens commun. Car il désigne par prévoyance non la capacité à prévoir, mais la capacité à agir alors même que le futur est imprédictible et que la science contribue à radicaliser cette imprédictibilité.

Mais l'action du dirigeant fayolien est aussi conçue comme une assurance collective qui permet de se prémunir contre les dangers connus et de garantir la régénération des forces pour des combats futurs inconnus. On retrouve alors le sens traditionnel de prévoyance. Fayol nous dit d'ailleurs que « les Français sont prévoyants mais que leur gouvernement ne l'est pas », parce que le régime d'action du gouvernement ne correspond pas au modèle fayolien.

Enfin, Fayol ne pouvait ignorer que prévoyance signifiait aussi entraide, solidarité et que le mot était inséparable de la justice sociale et de la cohésion nationale. Nulle surprise donc quand il développe ensuite l'idée que le chef d'entreprise doit réaliser « la constitution du corps social[39] », et « l'union du personnel[40] », car ce sont là des conditions du bon fonctionnement de son programme.

Avec ces deux notions on est loin du vocabulaire classique d'un gérant et d'un patron, et *a fortiori* d'un marchand. On est plus proche de la figure de l'administrateur public, qui n'oublie pas que son action participe de la construction d'un espace politique. Le chef d'entreprise fayolien construit ainsi une figure inédite qui :

- étend considérablement l'action du patron et du gérant en introduisant l'inconnu, la science et la recherche de perfectionnement ;
- importe dans la sphère privée une théorie politique de l'action et de la constitution du corps social.

On voit comment Fayol introduit une rationalité responsable qui nous est aujourd'hui familière : nous attendons que les entreprises innovent, qu'elles investissent dans la recherche, dans de nouveaux produits, dans de nouvelles compétences.

Mais avant Fayol, rien n'assignait ce type de tâche à un patron, un administrateur ou un gérant d'affaires. Fayol aboutit aussi implicitement à une critique nouvelle et profonde de

39 H. FAYOL, « Administration industrielle et générale », *Op. cit.*, p. 4.

40 *Ibid.*, p. 5.

la rationalité de l'*homo œconomicus*, car celle-ci se révèle inopérante face au nouveau type d'inconnu créé par la science.

In fine, Fayol invitait, sans le dire, à considérer l'entreprise issue du nouveau monde industriel comme un nouveau type d'entité collective, qui transforme simultanément les fondements du savoir, de l'économique, du social et du travail. Cette nouvelle entité ne pouvait être gouvernée que selon une conception réinventée du chef et de la bonne administration.

4. Conclusion : Fayol, théoricien d'un modèle créatif/politique

Fayol a trop souvent été lu sans discussion préalable sur l'appareil critique, linguistique et interprétatif nécessaire à son étude. C'était oublier que Fayol était un savant renommé et un innovateur remarquable. C'était négliger aussi le contexte de son œuvre et l'ambition théorique qui sous-tendait son projet. Notre relecture confirme cette ambition et l'ampleur des moyens conceptuels mobilisés par Fayol. La mise au jour de cet édifice intellectuel est porteuse de multiples enseignements.

4.1. La théorie administrative fayolienne n'est pas une somme de recettes universelles, hors du temps

Elle prend acte d'un tournant historique majeur : la formation de nouveaux rapports entre science, industrie et travail. Ces nouveaux rapports inaugurent un régime inédit de renouvellement des richesses. Ils favorisent aussi de nouveaux collectifs, dont la nature et le gouvernement sont problématiques. En théorisant un nouveau type d'autorité, Fayol contribue à la domestication de ces nouveaux collectifs, il permet la formation d'une nouvelle épistémè (au sens de Foucault), celle du « chef d'entreprise moderne », qui rend visible l'entreprise moderne elle-même. Cette dernière n'est plus l'ancienne compagnie, elle n'est pas non plus assimilable à une organisation bien réglée comme les administrations d'État.

4.2. La théorie fayolienne ne doit rien à la théorie économique, pas même à celle de l'entrepreneur.

L'absence des notions économiques les plus élémentaires (profit, marchés, capital[41]) aurait dû être mieux soulignée. Car on peut difficilement accuser Fayol de ne pas connaître la réalité de la vie des affaires. Il faut donc prendre cette absence au sérieux. Ce point mériterait une plus longue discussion mais on peut retenir, au terme de cette étude, deux raisons qui éloignent Fayol de la théorie économique.

Fayol considère que la source majeure de la création de la richesse n'est ni dans le capital, ni dans le travail, ni dans les moyens de production, mais dans la recherche scientifique et dans le perfectionnement permanent. Fayol invite donc à penser une rationalité créatrice,

41 En dehors d'un tableau comptable sommaire, H. FAYOL, « Administration industrielle et générale », *Op. cit.,* p. 54-55.

distincte de la rationalité fins-moyens de la pensée économique, qu'il s'efforce de décrire avec les concepts de prévoyance, d'inconnu, et de programme[42].

Cette rationalité créatrice ne peut se déployer que dans de nouveaux systèmes collectifs de travail dont il faut inventer le mode de gouvernement. Fayol ne remet en cause ni l'économie de marché, ni le contrat de travail, il reconnaît même l'intérêt des incitations économiques. Mais les organisations héritées du monde marchand ancien sont à ses yeux incapables de réaliser «les programmes d'action» dans l'inconnu qu'exige le nouveau monde industriel. Il faut donc inventer de nouveaux liens sociaux, et cette tâche incombe aussi à ce nouvel acteur politique qu'est le chef d'entreprise. C'est sur ce point qu'il prend appui dans la philosophie politique de son temps et dans l'héritage des Lumières. Il y trouve le projet général de perfectionnement qui constitue la promesse collective sur laquelle une société peut se constituer et s'unir.

4.3. L'inventivité théorique de Fayol a été sous-estimée.

Pour mieux apprécier la portée des concepts fayoliens, on peut les rapprocher de deux autres auteurs, Franck Knight et Max Weber, qui sont ses contemporains et s'efforçaient aussi de penser les transformations du monde industriel de la période. L'économiste Franck Knight[43] repense la nature de l'incertitude dans le fonctionnement économique. Il reconnaît l'existence d'une incertitude non probabilisable qui invalide la théorie classique des marchés. Knight en conclut que le fonctionnement économique devient dépendant de «managers» qui ont pour fonction de prendre des décisions en situation d'incertitude radicale. La valeur économique de ces managers réside alors, selon Knight, dans la réduction des incertitudes qu'ils réalisent pour l'économie dans son ensemble. Néanmoins Knight ne réussit pas à justifier l'investissement dans la recherche, au niveau d'une entreprise, et il ne propose aucune théorie du fonctionnement de l'entreprise : celle-ci reste une simple réunion de travail et de capital. Le sociologue Max Weber[44] pense l'émergence de l'organisation économique, notamment à travers la théorie dite rationnelle/légale. Dans ce modèle, la rationalité prédominante est instrumentale (adaptation des moyens aux fins) et la vie sociale est construite sur l'impersonnalité des lois et des règles. Ces deux caractéristiques décrivent des organisations de type bureaucratique ou technocratique.

Le modèle fayolien se confond-il avec le modèle weberien ? Une lecture trop hâtive du traité a pu laisser penser que Fayol décrit une bureaucratie. Mais Fayol indiquait lui-même qu'il s'opposait au type d'administration qui domine dans les organismes publics parce qu'elle n'avait pas de programme d'action et pas de prévoyance. Par ailleurs, dans le modèle fayolien, la constitution du corps social n'est pas seulement le résultat de règles impersonnelles, seraient-elles source de justice, mais exige aussi le perfectionnement collectif et individuel. Enfin, l'entreprise fayolienne n'est pas une technocratie parce que l'autorité n'y est pas détenue par la fonction technique. Ce point est au cœur du modèle fayolien puisqu'il vise

42 Il n'hésite pas à comparer le chef d'entreprise à un architecte lorsqu'il s'agit de concevoir le programme.

43 F. H. KNIGHT, *Risk, Uncertainty, and Profit*, New York, Sentry Press, 1921.

44 M. WEBER, *Économie et Société*, Paris, Plon, 1971 [1921], rééd., Paris, Pocket, 1995.

précisément à inventer un gouvernement de la fonction technique et de la recherche, au même titre que pour les autres fonctions de l'entreprise.

Une conclusion s'impose : Fayol aboutit à un modèle que nous proposons d'appeler « créatif/politique », par comparaison avec le modèle rationnel/légal de Max Weber. Ce modèle se révèle à l'analyse plus adapté au nouveau monde industriel, scientifique et innovateur, que les théories de Knight et de Weber qui ont eu pourtant une réception scientifique beaucoup plus large que Fayol. Avec le recul de l'histoire, la confrontation à ces deux auteurs permet de cerner la logique profonde de la découverte fayolienne. Fayol n'est prisonnier ni du rationalisme économique d'un Knight ni du structuralisme sociologique de Max Weber. Son modèle prend ses racines dans l'idée que la quête permanente de progrès et le développement continu des sciences plongent les sociétés modernes dans un univers où le futur est doublement inconnu : il est inconnu du fait des autres, mais il est aussi inconnu du fait de soi. Dans cet univers, la rationalité des décisions n'a plus de socle épistémologique assuré : compte surtout la capacité à mobiliser pour inventer et à découvrir, ou, réciproquement, la capacité à inventer et découvrir pour mobiliser. Le chef d'entreprise devient le capitaine d'une expédition dans une contrée largement inexplorée. Dans une telle expédition, la cohésion sociale joue un double rôle : elle aide à construire le programme d'action en mobilisant les connaissances de tous, mais elle aide aussi à le mettre en oeuvre une fois qu'il est fixé. Fayol aurait donc été le premier penseur à comprendre que la dynamique des entreprises annonçait la fin des théories classiques de l'économie et du système social, pour le meilleur et pour le pire.

Et aujourd'hui ?

Le capitalisme financier a provoqué une étrange régression anti-fayolienne dans un monde qui n'a jamais été aussi fayolien. La dimension créative n'a jamais été aussi nécessaire et présente dans la compétition contemporaine par l'innovation. De même que la dimension politique de l'action du chef d'entreprise s'étend à un « corps social » qui va au-delà des personnels et des actionnaires, et inclut des partenaires, des territoires, des États, et des milieux écologiques. Le concept de perfectionnement est passé de l'histoire humaine à celle de la planète.

À l'inverse, financiers et codes de gouvernement d'entreprise (ou corporate governance) ont favorisé depuis trois décennies le retour d'une néo-gérance, exacerbant l'alignement du dirigeant sur les seuls intérêts des actionnaires. Les effets corrosifs et destructeurs de cette régression sont aujourd'hui patents. On observe un divorce croissant entre entreprise et société (au sens des associés) mais aussi entre les entreprises et les États. Retrouver la pensée fayolienne, ce n'est pas appeler à une illusoire restauration, un siècle après, du type de dirigeant qui fut le sien. Mais la valeur du modèle fayolien tient à ce qu'il offre une alternative théorique oubliée aux erreurs du rationalisme économique, et à la rigidité des structuralismes sociaux. Il permet de penser le gouvernement des actions collectives créatrices. Comme beaucoup de grandes pensées du passé, il offre des pistes pour l'avenir.

FINANCING THE NEXT GENERATIONS OF INNOVATION: NEW DIMENSIONS IN THE PRIVATE EQUITY MODEL

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Financing the Next Generations of Innovation: New Dimensions in the Private Equity Model

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ABSTRACT

It is widely acknowledged that, for firms to grow, they need to regularly introduce new generations of innovation; however, this is rarely addressed in the finance or private equity literature. If the private equity investment class is structured based on the business cycle, little is known about how it fosters firms' capacity to regenerate. This leads to the question: How can private equity support firms' ability to repeatedly innovate? Building on the literature in innovation management and design theory, we propose complementing private equity models with new dimensions: the design of potential future products and their expected value. This model is used to analyze in-depth a longitudinal case provided by a French investment fund. We show that it is far better suited to certain investment strategies than are classical models. Among other important implications, we suggest that private equity must

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not only provide seed, venture, or buyout capital, but also support firms' innovation portfolio regeneration.

KEYWORDS: Financing Innovation, Private Equity, Innovation Management, Middle-Market Firms, Design Theories, Firm Life Cycle, Value of Firm

JEL CODES: G320, O32

The ability to adapt to fast-paced business change has become critical for firms' competitiveness and growth. There are several ways through which firms can occasionally increase their performance, but none is as important over the long term as the development of an ability to sustain innovation. There have been extensive research efforts to understand the drivers behind a firm's capacity to continuously innovate, especially in the fields of innovation management and design theories. Despite this, there remains a need for research in finance to integrate these developments, especially in clarifying the correlation between repeated innovation and private equity investment, not limited to venture capital (VC) (Bertoni, 2017).

Indeed, while the innovation management literature insists on the need for firms' regular renewal (Jelinek *et al.*, 1993; Le Masson *et al.*, 2010b; O'Connor, 2008), private equity support for firms' regeneration strategies has received scant attention. Private equity consists of equity securities of non-quoted companies with high potential over the medium-to-long term (EVCA, 2007; Invest Europe, 2018). Its support of innovation has largely been linked to start-ups, which mostly sustain a first and one-off innovation. Private equity is, however, also prominent in more mature firms, through the practice of buyout, and these firms also face the challenge of regeneration, given current challenges in innovation. Despite this, the bulk of the buyout literature focuses on the impact of leveraged buyouts on portfolio companies, or the drivers of successful investment strategies, while minimizing reliance on innovation to facilitate such strategies. Overall, apart from a few recent studies linking entrepreneurship and buyouts, there remains a lack of a conceptual framework and methods by which private equity investors can foster value creation through corporate innovation in mature firms (Mazzucato, 2013).

Private equity is a funding source that public policies have used to support economic growth and that Invest Europe now presents as a way to "*build better businesses*". The recent sharp increase in the amount of capital available (McKinsey, 2018) and the difficulty of ensuring high returns from financial engineering alone has led to investors' renewed interest in entrepreneurial growth (Torres, 2015); hence the value of clarifying the role of investors in fostering corporate innovation.

The present study therefore addresses the following research question: How can the private equity mode of investment support repeated innovation, especially in mature firms?

The design theory literature insists on the crucial role of regeneration processes, not only limited to knowledge expansion but also integrating the exploration of unknown concepts. We show that current literature on private equity practices and related models has scarcely considered this approach. We conduct an exploratory case study in partnership with a French state-owned investment fund. Specifically targeting middle-market firms, the fund has been operating since 2014 and benefits from 3 billion euros in assets under management. We single out an investment toward an innovative firm which confirms that this framework explains certain innovation-based investment practices that have not yet been modeled. We build on this empirical analysis to complement the private equity approaches by modeling another mode of investment better suited to fostering repeated innovation; we call this "regeneration capital". This investment model has distinct characteristics in terms of target selection, valuation, and post-investment strategy, resulting in various theoretical and managerial implications.

Accordingly, the paper comprises four sections. In the first section, we analyse the relevant academic literature. The second section details the case study methodology. The third section focuses on case study description and results. Finally, the fourth and fifth sections set out a discussion, implications and limitations.

Literature Review: Private Equity Support for Corporate Innovation

The literature on innovation has already thoroughly investigated the conditions of a sustained regeneration process. In this section, we first present the theoretical framework of our analysis that we derive from this literature on innovation management and design theory. Then, a review of private equity literature highlights the limitations of private equity models to assist such renewal. We show that this literature does not yet fully capture the variety of interesting and innovation-based practices that actual private equity funds use in their activities.

A Framework for Clarifying the Relationship between Innovation and Private Equity Investment

Innovation has become a major issue with regard to firms' competitiveness in the light of a more fiercely competitive environment and rapidly changing markets. Over the past few decades, management researchers have devoted a great deal of attention to differentiating various innovation dynamics, and to characterizing the organizational structures and management practices that generate them.

The main empirical evidence driving this research field is that no long-term success is built on a one-off innovation. Abundant research has stressed the need for developing a capacity to repeat innovation to create sustainable long-term value. Evolutionary theories have long emphasized the role of cumulative learning relying on the development of organizational capabilities (Nelson *et al.*, 1982; Nelson *et al.*, 2002). Building on Penrose's seminal work, the resource-based view of literature also insists on the crucial ability of a firm to develop strategic resources that are able to enhance a firm's competitive advantage (Van de Ven *et al.*, 1999; Hamel *et al.*, 1994; Nonaka, 2000; Penrose, 1959). Research on dynamic capabilities has emphasized the need to continually extend and renew the firm's resource base to adapt to the changing business environment and consequently sustain a competitive advantage (Cohen *et al.*, 1990; Teece, 2007). To some authors, the quest for sustainable growth even depends directly on firms' ability to identify and combine the microeconomic drivers of their persistent innovation; for example by systematically coupling product and process innovation (Bianchini *et al.*, 2018; Le Bas *et al.*, 2014).

Given that the regular renewal and management of exploratory processes are fundamental to every firm's long-term survival in contemporary economies (Jelinek *et al.*, 1993; Le Masson *et al.*, 2010b; O'Connor, 2008), design theories were developed to provide systematic approaches to organizing regeneration processes, especially in mature firms (Le Masson, *et al.*, 2018). Recent advances in design theories, and concept-knowledge (C-K) theory in particular, offer an integrated framework to explore the organizations and processes required to sustain innovation capabilities (Hatchuel *et al.*, 2006; Le Masson *et al.*, 2017b). Their main contribution is to highlight that any innovative design process, aimed at forcing the existence of new – hence previously unknown – objects (*e.g.* products, services, organizations), requires not only the creation and expansion of knowledge (learning, optimizing, absorbing external knowledge), but also the regeneration of associated "imaginaries", or concepts; *i.e.* the design space in which designers work on the desirable potential properties of future new objects.

This discovery entails at least one pivotal practical consequence for organizing sustainable innovation: the requirement for a concept regeneration process not limited to the acquisition of new knowledge. It has led researchers to produce an integrative framework based on the difference between two distinct "design regimes"; one based on established design rules, wherein new products and services can be described using existing and stable performance criteria, and designed using the least new knowledge possible; and an innovative design regime, wherein the identity of products and services to be designed are greatly regenerated, thus prompting the need for radically new competencies and knowledge, and renewing the imaginaries used to represent future desirable objects.

In the first design regime, the development of new competencies and products happens gradually. New objects are part of lineages sharing common attributes and emerging from the exploration of stable knowledge bases in known directions (Hage *et al.*, 2006). In economics, ruled-based design relies on a rationale of uncertainty reduction; for example, through the usual marketing, testing and validation tools. This development phase is mostly based on already identified knowledge and competency fields; this is why we will call the design activities in this regime "K-products" (in which K means "known").

However, the innovation-intensive economy requires companies to adopt an innovation design regime with increasing frequency (Le Masson *et al.*, 2010a), wherein only refining existing concepts or products is not sufficient. Companies, to substantially renew their activity, must simultaneously explore unknown paths, break away from existing design rules, define new value, expand competencies, and generate new opportunities. In practice, this development relies on firms' exploration of the unknown properties of their future products to regenerate innovation fields and performance criteria. This phase relates to fuzzy front-end (Koen *et al.*, 2001), ideation, creativity (Le Masson *et al.*, 2017a; Lerch *et al.*, 2015), regeneration of imaginaries (Agogué, 2012), and expectations (Le Masson *et al.*, 2013). Contrary to already identified knowledge fields in the first design regime, here it generates objects (*e.g.* ideas, concepts, technologies) aimed at expanding the firms' competencies, and requires a transformation into actual products and services, such as through research and development steered by innovation fields. In this stage, the concept is embodied in the promise of a product to be developed; one that has specific value for the firm and which would ultimately constitute a new head of lineage (*i.e.* first of a product lineage). We will call this promise an "unknown product" (U-product). Substantial financial support can be required for areas such as prototyping or acquiring key technologies or competencies.

With this vocabulary, sustaining an ability to repeatedly innovate requires not only sustaining the launch of K-products but also regularly designing U-products and consenting to related organizational efforts and development costs. In other words, merely converting U-products into K-products cannot support repeated innovation over the long term. On the investor side, sustaining U-product generation requires, in addition to the mere provision of financial resources, new competencies in terms of identification, valuation, and support.

We explore whether the literature analyzing private equity investment practices in mature innovative firms also described similar systematic approaches.

Limits of Current Private Equity Models for Financing Mature and Innovative Firms

The view of innovation as a life cycle has clearly strongly influenced the organization of private equity, as its asset classes are currently structured around business cycle stages, from young and innovative firms to mature companies (Berger *et al.*, 1998; Miller *et al.*, 1984; Quinn *et al.*, 1983). First, equity venture funding refers to private equity investments made for the launch (seed capital), the early development, or expansions of start-ups (EVCA, 2007). Then, buyouts, in a broad definition, encompass deals usually financed through a combination of equity and debt (Berg *et al.*, 2005; Wright *et al.*, 1994) aimed at supporting a firm's growth and maturity. At the end of the cycle, a third model, turnaround capital, addresses investments in distressed firms. Buyouts and VC (including seed and later stages) have attracted most of the attention in the private equity literature (Broere, 2013; Glachant *et al.*, 2008). Researchers have characterized these distinct practices, and their relationship to innovation, which are grounded in various theoretical models.

Buyout Investments Do Focus on Mature Firms but Value Growth Scenarios on Known Projects

The buyout literature suggests investors neither select innovative firms nor endeavor to enhance innovation capabilities once acting as shareholders. Unlike with venture capitalists, it is well established in academic literature that buyout investors target mature and stable companies. As clearly stated in the *Harvard Business Review*, buyout investors "*don't invest in firms known* *for innovation*", but rather they "*are looking for companies that are dominant in a market, aren't risky, and have a predictable and steady stream of cash to pay back debt*" (Torres, 2015). That aside, studies focusing on investors' value creation levers have historically emphasized operational and financial engineering as efficiency mechanisms to improve financial performance (Bassoulet, 2015; Gompers *et al.*, 2016b; Holmstrom *et al.*, 2001). Thus, buyout transactions have conventionally been associated with cross-cutting activities, short-termism, and downsizing workforce (Harris *et al.*, 2005; Wright *et al.*, 2001; Wright *et al.*, 2009). These rationalization strategies depicted in the literature, although they generate strong returns for investors, are often accused of damaging research and development (R&D) efforts and, more generally, innovation capabilities (Nadant, *et al.*, 2011). Even though some other value creation levers, such as internationalization, digitalization, and product development (Berg *et al.*, 2005; Bruining *et al.*, 2002), have recently been mentioned, researchers regret the scant attention devoted to strategies that would invest in innovation and enable entrepreneurial growth (Meuleman *et al.*, 2009; Toma *et al.*, 2017; Wright *et al.*, 2001). Consequently, there is a call to renew the historical strategies mostly based on optimization (Baker *et al.*, 2012; Hersh, 2018).

Empirical literature has studied correlations between buyout investment and standard indicators for corporate innovation. Researchers have looked for evidence of the fact that leveraged buyout transactions would not systematically hinder innovation capabilities. The impact on resources allocated to R&D, through measurements of amount and efficiency, has been discussed and has had mixed results. Regarding the output of innovative activity, there would be no impact on the number, originality, and genericity[2] of patents, while patent portfolios would on the whole be more focused (Amess *et al.*, 2015; Kaplan *et al.*, 2009; Lerner *et al.*, 2011). Such patent portfolio management seems consistent with a focus on core competencies as depicted in the resource-based view literature. Building on path dependencies, new activities are deduced from previous ones thanks to "local" exploration spaces (O'Connor, 2018), whereas substantially renewing a firm's activity requires the exploration of unknown paths.

Current valuation methods prove consistent with low-uncertainty buyout development strategies. Despite the key role discounted cash flow methods play in firm valuation in academic finance courses, recent research has shown that buyout investors would rather rely on a gross internal rate of return, a multiple of invested capital and, to a lesser extent, comparable

2. An original patent quotes patents from various patenting classes. A generic patent is cited by several other patents from a distinct patenting class (Lerner *et al.*, 2011, p. 453).

approaches (Gompers *et al.*, 2016b). Compared with the discounted cash flow method, they all set aside the complex issue of discount rate choice. However, all these valuation methods share the need to assess a firm's current and future earnings given its existing products and an extrapolation of its future developments, thus making forecasts of future profit streams (embodied by free cash flows or EBITDA) a key variable. Due diligence processes have been formalized to estimate the probability that business plans will be accurate. In practice, these methods are known to be less reliable with regard to innovative companies that have the potential to develop yet-unknown products targeting unknown markets. The comparable approach compares the firm with others possessing the same characteristics (*e.g.* same sector, size, region, structure). The more innovative a firm, the harder it is to find comparable activities or transactions or to extrapolate future cash flow from past activities. To sum up, the academic literature shows that buyout investors prefer to target stable companies likely to increase their revenues through low-risk development strategies (CAIA Association, 2018; Torres, 2015). Financial valuation approaches stemming from historical corporate finance models serve such targets and strategies accordingly.

The established buyout model has therefore been encouraging and valuing low-uncertainty strategies with limited consent to invest in non-productivity-oriented development costs; thus casting doubt on buyout capital's ability to nurture new capabilities other than upgrades. The valuation process values growth scenarios on known projects, even if they are still uncertain, such as the optimization of existing activities, operational and financial engineering, or certain types of build-up. Consequently, based on our framework, we identify that buyout capital mainly fosters K-products either by optimizing already existing ones or by providing additional production capacity.

Buyout investments, although they target mature firms, prove to be limited at supporting innovation. On the contrary, entrepreneurial equity models, such as venture or seed capital, are known to be tailored to young innovative firms. We therefore investigated the related literature to identify if entrepreneurial equity models sustain U-products, and if they could help in supporting mature firms' renewal.

Entrepreneurial Equity Investment Models as a Potential Resource

In the private equity asset class, entrepreneurial equity financing is distinct when considering the topic of innovation as it targets start-ups, which are known as strong drivers of disruptive innovation in the contemporary economy (Timmons *et al.*, 1986). An extended study of the relationship between sources of capital and innovation is a core issue of entrepreneurial finance literature (Cumming *et al.*, 2017; Cumming *et al.*, 2018). During the first development stages, firms face extreme difficulties in contracting loans because of high uncertainty related to their activities, a lack of tangible assets to be used as collateral (Williamson, 1988), and substantial information asymmetry (pecking order theory, Myers, 1984). Therefore, among private debt, trade credits, initial public offerings, crowdfunding, business angels, and private equity funds, the latter two funding tools have been recognized as vital elements for young firms' development.

Private equity intended for young firms includes all equity financing from the firm's birth until it has commercialized its first products, got out of the Death Valley by becoming profitable, and expanded. In practice, venture capitalists share the same investment steps as those modeled by Tyebjee and Bruno (Tyebjee *et al.*, 1984). This broad category encompasses a range of funds, investing from early (seed) to late stages (series C/third round), and ending with growth capital. Venture capitalists' investment practices are grounded in several theoretical models.

We deduce from the literature that the late-stage VC investor role is oriented toward one-off innovation development. Investment decision-making determinants have been discussed extensively, which has led to the identification of two key variables: business characteristics (investors seek proof of technological maturity and market reality (Bhidé, 2008; Eckhardt *et al.*, 2006)) and management teams; the latter being the most important for selection and ultimate success (Gompers *et al.*, 2016a; Gompers *et al.*, 2016b; Khanin *et al.*, 2008; Knockaert *et al.*, 2010). More precisely, it appears that VC mainly provides funding to complete development and accelerate the commercialization of creative concepts (Hellmann, *et al.*, 2000). Several studies show that venture capitalists select innovative companies with the objective of helping them in the commercialization process, rather than to generate further innovations (Rin *et al.*, 2013; Rin *et al.*, 2017). As mentioned in (Rin *et al.*, 2007): "*Venture capital would therefore finance companies whose innovation strategies are already well developed, with the perspective of turning them soon into 'cows'*".

Venture capitalists not only assume a role of scouting, selecting, and funding promising start-ups, they also provide coaching. Although some business angels are not actively involved in the invested firm, most consider their post-investment contribution to be critical (Landström *et al.*, 2016) and provide strategic input, such as by taking positions on the venture board or by becoming consultants (Cumming *et al.*, 2018). First, for all VC stages, researchers cite investors' networks and brokering capabilities as assets for start-up success, but often without linking this precisely to innovation strategy. Venture capitalists also share a model of innovation acceleration, known as the Lean Startup model (Ries, 2011), which has recently attracted a great deal of attention from researchers and practitioners (Engel, 2011). This business development methodology aims to find an appropriate market for an existing product to reach initial success by trial and error, adjustment, and development techniques. When facing a dead-end, start-ups have no other choice than to pivot. The existing research on pivoting is limited and some examples suggest a type of pivot involves altering the product–a market fit without launching a new U-product, which would also cause significantly stronger organizational issues for a mature firm.

Regarding valuation rationale, one challenge lies in the underlying pricing calculation method. At later stages, when funding marketing, product improvement, or major expansion, venture capitalists use earning or market value approaches (Gompers *et al.*, 2016a) because an asset-based approach does not account for a firm's future growth. However, market value approaches (comparable transaction methods) are difficult to apply, as finding comparable firms for highly innovative activities can be challenging. Theoretical finance models based on cost and revenue forecast[3] results (the earning value approach) also lack accuracy for start-ups because of remaining uncertainties regarding future growth. Investors usually focus on estimating future revenues while paying less attention, or having difficulty assessing, the required reinvestment and operating expenses (Damodaran, 2009). Practitioners have tailored further methods, among which are convention-based (Damodaran, 2009; Meunier, 2017) or real option frameworks. The convention-based approach aims to estimate remaining development costs until the firm reaches a break-even point. It therefore circumvents the issue of precisely forecasting future revenues related to yet-unknown activities and hypothesizes that they will have adequate significance to ensure a return on investment. This strategy mostly relies on the incubation of existing projects, with the hope that they include "golden nuggets", *i.e.* a portfolio strategy wherein the small percentage of successful invested-in firms should compensate for the failure of all the others and ensure the investor a financial return. These targets are expected to achieve extremely high profits; for mature firms, this would question the value of sustaining historical activities. The real option framework has then been designed as a multi-staged financing tool to aid decision-making under uncertainty. It allows the creation of an option for unblocking

3. For example: discounted cash flow (DCF), internal rate of return, net present value, and the top-down approach (which is derived from DCF), Damodaran, A. (2009), *Valuing Young, Start-Up and Growth Companies: Estimation Issues and Valuation Challenges*, New York University, *ibid*.

financing that depends on future learning and is based on a defined decision space. In practice, few venture capitalists use real options, perhaps because of this inconsistency between the radical uncertainty faced by start-ups – even more at the early stage when dealing with U-products – and the requirement of a pre-designed decision space (Dubocage, 2006).

At the earliest stages after the ideation phase, when funding the first proof of concept, investors face both an unknown technology and an unknown market (Huang *et al.*, 2015). Departing from frameworks on decision under uncertainty, seed investing would refer to frameworks on decision under the unknown. This could explain why a "gut feeling" is often used to describe business angels' investment decisions (Gompers *et al.*, 2016a). Indeed, although research on business angels identifies characteristics of the entrepreneur as key determinants for target selection, decision-making criteria remain a topic of ongoing research (Drover *et al.*, 2017). On the whole, business angels use fewer formal contracts, control, and due diligence processes. They prefer to rely on expertise-based intuitive evaluation that has been demonstrated to lead to the selection of more successful investments (Huang *et al.*, 2015). An empirical study focusing on business angels' post-investment practices concludes that predictive strategies through business plans or market analysis are proven to be less efficient than non-predictive control strategies (Wiltbank *et al.*, 2006) attained through "*a means focus, affordable loss investing, pre-committed partners, and leveraging surprise*" (Wiltbank *et al.*, 2009). If start-ups obtaining seed capital work on refining their U-product, it seems investors lack a systematic approach to select and support them. Business angels usually make smaller stakes at the earliest stage of a firm's development and expect most of their decision to be complete losses.

Finally, abundant literature has analyzed VC investment's impact on backed start-ups' innovation output, in a search for ex-post correlation or causality. For example, a stronger propensity to patent was found in VC-backed companies in the United States (Kortum *et al.*, 2000), but the same did not hold true in the European context (Freeman *et al.*, 2007). In another direction, the numbers of new products and instances of VC funding have been shown to be correlated (Peneder, 2010). Very few studies have analyzed how investors influence start-up innovation strategy by making use of advances in innovation management to characterize this.

Based on this literature review, we conclude that the dominant models of private equity investment described in the literature (seed, late-stage VC, and buyout) do not address the need to support innovative firms' regular regeneration. The design theory framework sheds new light on the relationship between the various private equity asset classes and corporate innovation.

Buyout capital mainly fosters the launch of K-products because of optimization strategy or increased production capacities. Entrepreneurial equity is described as addressing U-product development in two different ways: seed capital sustains U-product maturation, that is, the promise of refinement, while late-stage VC supports its conversion into a K-product that generates actual turnover. The rise of development strategies such as spinoff, incubators, or corporate venture could be an attempt to adapt entrepreneurial investment strategies for mature firms. Based on a decoupling of firms' historical and innovative activities, this suggests investors lack models to organize and value internal self-sustaining renewal.

Overall, we conclude from the literature that no existing private equity asset class would support the repeated generation of new waves of U-products. Figure 1 summarizes the main practices and models of private equity investment and their impact on corporate innovation.

Figure 1 **– Relationship between innovation regimes and investment practices of private equity investments, extracted from the academic literature**

	Seed capital	**Late-stage venture capital**	**Buyout**
	ENTREPRENEURIAL INNOVATION INFORMAL AND NON-PREDICTIVE APPROACHES	**CONCEPT DEVELOPMENT** DECISION UNDER UNCERTAINTY	**OPTIMIZATION** FORMAL VALUATION METHODS
Target selection	Very-early-stage firm, "informal" methods, ongoing research (Drover, Busenitz et al. 2017)	Selection and scouting: young firms with high growth potential with an already defined creative concept and strong management team (Eckhardt, Shane et al. 2006)	Stable and mature firms with growth potential (Torres 2015)
Valuation	Small stakes, "gut feeling", expertise-based but still intuitive valuation rationales (Huang and Pearce 2015, Gompers, Gornall et al. 2016)	Convention-based approaches, market and income approaches (Damodaran 2009, Gompers, Gornall et al. 2016, Meunier 2017)	Theoretically: market and income approaches (comparable, DCF) Empirically: IRR and multiple invested capital (Gompers, Kaplan et al. 2016)
Post-investment strategy	Coaching - Seed: diversified, mostly active investors (White and Dumay 2017) - Later-stage VC: faster commercialization (Hellmann and Puri 2000, Rin and Penas 2017) Resource provision (network…). Innovation acceleration and lean start-up as adjustment techniques (Engel 2011)		Operational and financial engineering (Holmstrom and Kaplan 2001, Berg and Gottschalg 2005, Wright, Amess et al. 2009, Nadant and Perdreau 2011, Bassoulet 2015, Gompers, Kaplan et al. 2016)
	Monitoring: better efficiency of non-predictive control strategies (Wiltbank, Read et al. 2009, Landström and Mason 2016, Cumming and Groh 2018)	Monitoring: management compensation	

A few studies contribute to characterizing other ways for private equity to invest in innovation. Yet buyout impact as an entrepreneurship stimulator is a buyout category that has attracted scant attention (Bertoni, 2017). Some less-common avenues of research have found evidence that buyout-backed firms can promote entrepreneurial investment opportunity (Amess *et al.*, 2016), but only if this is through management buyout (*i.e.* if the main investor is the management team already in place) (Bruining *et al.*, 2013). For example, one study emphasizes new conditions of an investor mindset for a buyout operation to foster corporate innovation, owing either to incremental changes or renewal (Wright *et al.*, 2001). Instead of controlling managers as in the traditional agency theories perspective, this entrepreneurial approach focuses on promoting innovative ones. Another study showed how a private equity investor may actively contribute to providing new organizational capabilities in the specific context of an already entrepreneurial family firm in need of structuring its governance (Di Toma *et al.*, 2017). That work, however, presented a restrictive hypothesis: the presence of managers with an entrepreneurial mindset. At any rate, empowering managers still does not give investors clues on how to identify them and specifically impact innovation strategy when entrepreneurial managers are not already part of the firm. On the VC side, a recent original study (Rin *et al.*, 2017) pointed out that investors urge firms to strengthen their absorptive capacity, thus their innovation strategy (Cohen *et al.*, 1990), by favoring "make and buy" R&D. However, these isolated studies demonstrate the continued lack of a conceptual model building on original investment practices that help to support repeated innovation by addressing the selection, valuation, allocation of invested funds, and support of the firm after the investment. Overall, a research gap remains on the relationship between modes of investment and corporate innovation dynamics enabling mature firms' renewal. Thus, in the present article, in line with the previous contributions on the relationship between investment and the firm's innovation dynamics, we address the following research question: How can the private equity mode of investment foster the development of a firm's capability to repeat and sustain innovation?

We assumed that some investors have developed such original investment practices. Therefore, we identified a potential candidate and conducted an exploratory case study based on a panel of its investment deals. The paper builds on one of its investment decisions which is especially illustrative. In the next section, we present the related research design.

Research Design

This research was carried out thanks to collaboration with the French state-owned investment bank that includes several private equity activities targeting mostly French start-ups, small- to medium-sized enterprises (SMEs), and middle-market companies. VC investments and mid- and large-cap teams report to distinct directors and these teams do not exchange methodology or views on any deal. As of early 2018, the investment bank had around 30 billion euros under management, with part of that already invested directly in 700 firms and indirectly in 300 private equity funds. The French public sector was responsible for 9% of private equity money raised by French funds during the first semester of 2018 (France Invest, 2018). Even if state-owned, the investment bank doctrine states that it should "*behave like a prudent investor operating under market conditions to serve public interest*". To do so, all deals occur in partnership with at least one co-investor (*e.g.* another private equity firm, family, industrial group, or individual entrepreneur).

We chose to focus on investments in middle-market firms. The interest of private equity investors in this quite new firm category has drastically increased in recent years, creating a new asset class focused on mid-cap investments. In 2012, the investment bank created the first French fund specifically targeting middle-market firms, with 3 billion euros in assets under management. Despite the growing weight of mid-cap investments in financial markets, an investigation into related investment rationales has been overlooked. Middle-market firms are defined as being positioned between SMEs and large ventures. There is no international standard, but main definitions set limits for annual turnover and the number of employees. For example, in France, this encompasses companies with an annual turnover below 1.5 billion euros and with 250-5000 employees. These account for a significant share of job and value creation, which is why they are known as pillars of the economy in countries such as Germany (*Mittelstand*), the United States, and France. Middle-market firms face the challenge of continually renewing their activities through repeated innovation to sustain their competitive advantage. They combine high-uncertainty activities related to their entrepreneurial mindset (Grandclaude *et al.*, 2014) while benefiting from a financial track record that provides a stronger ability to predict future revenues. Therefore, investigating current private equity investment practice in European middle-market firms, which are at the crossroads of buyout and VC, should reveal other models and enrich both literatures in buyout and VC.

To deal with middle-market companies' specific needs and issues, the French government in 2008 created a new statistical category for them and for identified actors, including the French state-owned investment bank, to act as investors able to fully support the companies' innovation capabilities.

Data Collection

We selected and analyzed a group of deals among those of the French investment bank's multi-sector funds specializing in mid-cap investments. These funds have invested in more than 50 firms since early 2009, soon after French legislation acknowledged middle-market firms as a distinct firm category. The sampling process was designed to provide firms with contrasting types to emphasize surprises and to single out significant parameters. We faced one main constraint due to the phases of re-negotiation that can arise during the investment cycle (related, for example, to exit or reinvestment). By that time, both firms and investors are reluctant to disclose information.

This study presents one significant investment case that gathers two main characteristics. First, among the group of selected deals, it is one upon which we could assemble a full dataset despite confidentiality constraints which often restrict data collection. Then it is the most striking case regarding the difference between investor reasoning and the theoretical investment model (Siggelkow, 2007).

We followed the research setting of an exploratory case study. The theoretical framework extracted from design theories enables us to highlight new elements of investment rationales observed in the investment case that have not yet been traced in the academic literature.

One interesting characteristic with regard to our research question is that the firm we studied faced two private equity transactions, each of which had no impact on the capital structure. Each time, this only consisted of transfers of stock ownership. Consequently, the firm did not benefit from additional financial resources that could have been used to finance innovative activities.

The partnership gave us the opportunity to investigate investment strategies, owing to access to a yet-unexplored pool of data[4]. We had unique access to contrasted data both from the investor side (interviews, due diligence, follow-up documents), and the firm side (interviews with the founder, management teams, research teams, and partners). Investors in charge of the deal have aided our understanding of the investment rationale. Meanwhile, direct access to middle-market firms has enabled better analysis of the innovation

4. Please refer to the annex for additional methodology insights.

strategies. We also triangulated these data with press articles and open-access patent databases.

Data Analysis

The case study focuses on an industrial company established in the 1990s which we have decided to rename NRJ. At the time of the last private equity deal, in 2015, as with 61% of middle-market companies, NRJ was employing between 250 and 999 employees (only 12% have more than 1000 employees, Bpifrance, 2015). The generated annual revenue amounted to a few hundred million euros.

The data analysis consisted first in re-enacting NRJ history through three foci: the firm's competitive landscape, design activity, and capital structure evolution. Then we characterized the rationales of the various investors involved.

We used a specific approach regarding the analysis of NRJ design activity. Since its creation, NRJ has been well known as an innovative firm because of its ability to repeatedly design new products and processes. In the case study, the specific firm policy of systematic patenting was found to play a key role in tracking regeneration strategies. We found that 13 patent applications have been filed since its creation; on the firm's direction and by searching in the Espacenet online patent-search platform. Patents include technical specifications, some functional requirements, use cases, as well as performance criteria of new products. An analysis of NRJ patents through the lens of the design theory framework enabled us to draw a patent family tree differentiating U-products from K-products.

The following section presents the case study. It first describes a standard reading of the case which fails to fully explain the French state-owned investment decision. Thus, we make use of the framework extracted from design theories to propose a more accurate interpretation.

Case Description and Findings

The empirical analysis starts with a standard reading of the firm's ownership structure history and the issue arising because of the exit of private equity shareholders. At this stage, confronted with the current framework extracted from private equity literature, and competing funds' offers, the investment of our French partner fund (PEFinnov) appears to have been over-invested. We then depict the firm's historical innovation and growth dynamics, owing to the framework extracted from the innovation management literature that unveils the distinct reasoning on U-products. This reveals the key role of the firm's regeneration capability and enables understanding and characterization of PEFinnov's original investment approach.

Standard Reading of the Case: A Valuation of Existing Products and the Risks of Declining Revenues

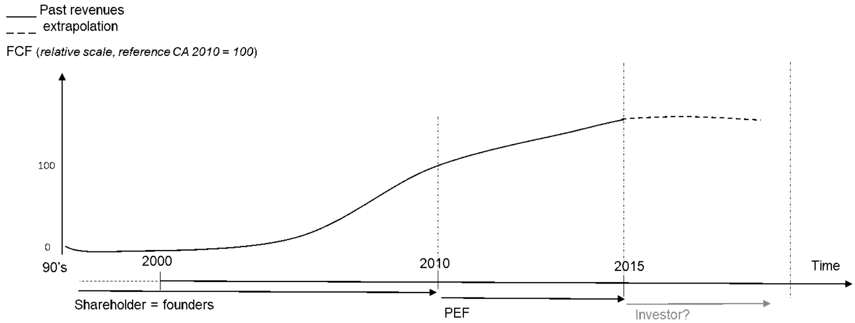
NRJ, established in the 1990s, manufactures and sells the core component of an energy production device. NRJ's first product resulted from a newly patented technology that gave the firm a sustainable competitive edge. Building on this first one-off innovation, intensive R&D activity generated a range of product families and improved the manufacturing process. This resulted in a steady revenue increase followed by an exponential increase in the mid-2000s, when new products were launched at the same time as the company underwent geographical market expansion.

Around 2010, one of the two founders sold their shares to a private equity fund (hereinafter PEF_0), which became the majority shareholder, thus substantially changing the historical shareholder distribution. After the average holding time of a private equity fund, 5 years, PEF_0 wished to exit. Among other private equity funds, the French one with which we collaborated considered the deal.

From 2015, a decrease in unit margins was forecast, owing to the products' obsolescence and competition. Indeed, multiple technologies coexisted on the market, the NRJ's technology being more efficient but without an irrevocable differentiator. Besides, NRJ technology addressed a narrow pool of international clients, some of whom could choose to insource. Nevertheless, volume sales were foreseen as increasing thanks to a growing underlying market, while CAPEX was anticipated to remain stable. Therefore, free cash flows were forecast to only slowly increase during the next holding period. This analysis is consistent with the literature on innovation management: absent any regeneration strategy on the offer of products and services of the company, "K-strategies" are at risk of becoming obsolete in a rapidly changing environment. This raised the question of how the company should be valued at that time (Figure 2).

Our interviews with the company's CEO, as well as press articles published at the time, show that, given this limited valuation potential over the following 5-year period, several private equity funds offered to purchase NRJ with the strategy of relocating production lines in lower-cost countries, and optimizing production costs. Again, consistent with the buyout model, this

Figure 2 **– NRJ ownership structure and free cash flow evolution from its launch until PEF_0 exit**



strategy focuses on rationalizing existing projects with stable knowledge and is not conducive to a repeated innovation strategy.

Following a strategic exchange with NRJ's CEO, PEFinnov agreed to purchase the company for the same price as the other funds were proposing but refused the relocation strategy and preserved the historical amount of R&D expenses and capital expenditures. Using the traditional valuation method, based on the extrapolation of previous cash flows, it appears that PEFinnov would therefore have over-invested to purchase NRJ. However, this French private equity fund is legally bound to do its utmost to ensure the best return on investment. The findings reveal that it valued something else.

Ex-Post Analysis of the Firm's Design History

By the time the NRJ founder wished to exit, NRJ was already a mature firm. Working on the innovative concept of an "instant product line" (U-product), major improvements in the manufacturing process duration had been made; decreasing it from more than one hour to just a few minutes. Since then, NRJ has mainly focused on product innovation. Managers have reported that each new product had systematically been protected by a patent application, which makes patent analysis an effective tracking tool for product innovation in this specific empirical case.

In-depth analysis of NRJ patents showed that NRJ's historical ability to continually renew its value proposition and formulate original concepts directly manifested itself in new patents, and then generated a head of lineage finally completed by related lineage extensions (K-products). The first historical product was optimized in terms of energy efficiency and improved compactness (*i.e.* volume and weight). NRJ also generated two new U-products (modular and easy-to-plug-in products), from which emerged two lineages that provided steady returns. Apart from the above, in 2010 other products based on new technologies NRJ recently patented were about to be launched. These were mature enough to enable, with low uncertainty, the quantification of remaining investments needed to finish their development, as well as related future income. This analysis of the period before PEF_0's investment demonstrates that NRJ already had some capabilities for developing innovative design strategies.

At the beginning of the holding period, PEF_0 did launch the new products. Although capital expenditure and R&D expenses remained stable, they were allocated to capacity and productivity improvement programs. Indeed, additional production lines were built, factories were extended, and some processes improved, while no additional patents or products emerged during the entire PEF_0 holding period (K-product optimization strategies). Free cash flow increased particularly because of an underlying booming market upon which the firm was well positioned, owing to environmental regulations favoring in-house technology.

Figure 3, based on a detailed patent analysis, shows the various design spaces that have been generated over time, and the related patents and products. Each dot represents the filing of a new patent. This clearly shows that while NRJ was prolific in terms of new concepts, new products, and related patents up until 2010, it stopped when PEF_0 invested. Furthermore, the average innovation cycle duration previously observed was short enough to track certain evidence, if present, of activity renewal during the PEF_0 holding period.

Another Valuation Approach Including Promises and Continued Reinvestment in Their Renewals

On the one hand, analysis of NRJ's design history demonstrates that PEF_0 took advantage of revenues extracted from products launched at the time of their arrival and invested to boost production capacity but that it did not pay attention to U-products' renewal and potential. Indeed, none were launched during the holding period. Moreover, in 2015, a written report resulting from the strategic and financial audit it ordered stated that no external growth or product development were considered for valuation assessment. In line with the buyout investment model depicted in academic literature, the deal attracted attention from various private equity funds that set a price with plans to relocate NRJs activities abroad to ensure a return on investment.

On the other hand, PEFinnov, while contractually mandated to return the same benefit as the others, invested at the exact same price, but declined relocation strategies. In other words, this strategy is inconsistent with the buyout optimization model depicted in the academic literature, which corroborates that the usual mode of investment and related valuation approaches are sometimes incomplete. Further analysis of PEFinnov's pre-investment documents and post-investment strategy highlights three new findings.

First, PEFinnov detected high-potential U-products unseen by other investors. NRJ's history showed its ability to design innovative products before the PEF_0 investment period, which notably gave birth to various patents and several successive lineages of products, although none were developed after 2010. An internal document edited specifically by PEFinnov mentions two new products under development as potential future business development streams.

Second, its post-investment strategy not only consisted of supporting K-product generation by rationalizing investments and costs on existing projects. During its holding period, it invested in R&D and capital expenditures resulting in U-product renewal. This point is crucial, as it highlights that the potential use of invested funds can differ from the buyout model.

Third, this strategy requires valuing U-products' potential and maturation. Traditional valuation calculation cannot account for the strategy followed in the regeneration model. Indeed, the buyout model values an extrapolation of existing projects in addition to increased cost efficiency linked to the relocation strategy. To be competitive the regeneration model assumes another

Figure 3 **– Patent analysis: new lineages generated and main products launched by NRJ from its creation until PEF_0 exited**

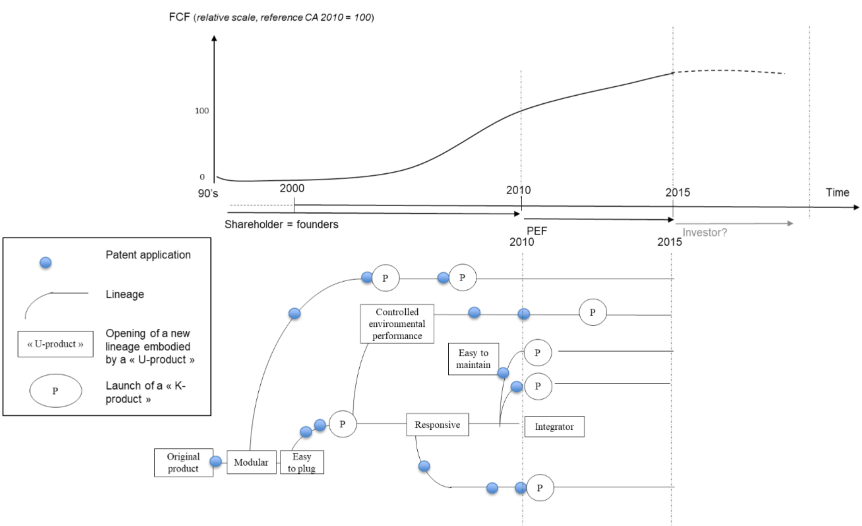
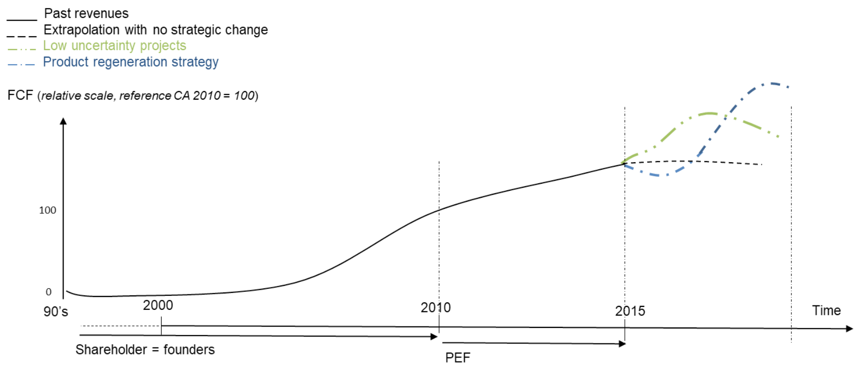


Figure 4 **– Forecast of free cash flow from 2015, owing to a private equity fund investment strategy**



type of added value. Data accumulated since 2015 show that two new patents were registered and one product was launched, prompting the hypothesis of a new lineage based on a new cycle of U-products. If this was the case, the valuation calculation for the regeneration model must include valuation of these new products. Therefore, this valuation would have been split into two parts: a usual extrapolation of revenues owing to existing products, and a premium resulting from exploration of the unknown, which the fund financed and supported. Figure 4 shows in green an example of the expected cash-flow returns following an optimization strategy and in blue the expectation of a strategy based on higher R&D and capital expenditures, with later earnings owing to new products and services.

Discussion

The Need to Account for the Renewal of Mature Companies in Finance

On the one hand, as described in the literature review and observed in the case study, standard private equity models for mature firms build on a firm's past activity extension. Investors prefer to target stable firms and to implement optimization strategies or finance low- uncertainty projects such as additional production lines. Accordingly, valuation is based on financial forecasts extrapolated from past activities.

On the other hand, the earlier stage investment models (*e.g.* early stage venture capital, business angels) sustain innovative product maturation or promise regeneration but lack a description of systematic approaches.

While U-product renewal is acknowledged as a key driver of a firm's long-term growth, none of the standard investment models account for its structured support in mature firms. The empirical case confirms the existence of some original investment practices not reflected in current tools (*e.g.* due diligence frameworks and valuation processes) and which do value innovation beyond traditional finance models. We contribute to supplementing the existing private equity models with an additional dimension: regeneration.

A Theoretical Model of the "Regeneration Model"

We aim at characterizing an investment model dedicated to mature firms and tailored to support their renewal.

To sustain a firm's renewal, design theories show that a concept regeneration process is required. Accordingly, they provide a vocabulary to differentiate promises of products to be developed resulting from this concept regeneration process ("U-products"), from already existing activities ("K-products"). We aim to integrate these promises that have specific value for the firm in the investment model. We propose a model that considers both forecasts extrapolated from past activity and premiums related to innovative design activities.

In addition to standard extrapolation methods, a quantifiable premium (Π) can be generated owing to the ability to identify, value, and support still partially unknown concepts (U-products) and related development costs. Building on the discounted cash flow valuation or comparable methods, valuation could be mathematically expressed in valuation calculation by:

$$Valuation_{(DCF)} = \sum_{t=1}^{N} \frac{FCF_{(existing\_products)}}{(1+WACC)^t} + \frac{VT}{(1+WACC)^N} + \Pi - debt$$

or

$$Valuation_{(Comparable)} = M * EBITDA_{(existing\_products)} + \Pi - debt$$

where Π represents the additional value owing to U-products beyond the traditional valuation methods found in existing literature. The value Π embodies the targeted value resulting from design activities to be deployed and which cannot be reached by uncertainty reduction.

The empirical analysis shows the challenge of identifying the yet-unknown products. For example, in the case study, the specific firm policy of systematic patenting has played a key role in tracking regeneration strategies; however, patents are not always available, and they can have various relations with innovation (Laperche, 2004). While renewing innovation indicators remains an ongoing research topic (Kerr *et al.*, 2015), evidence of innovative design efforts can already be found in individual cases by tracking patents and acquired licenses, prototypes, or the topics of external collaborations (*e.g.* institutional cooperation programs, inter-firm partnerships, crowdsourcing).

Regeneration Capital: Implications for Corporate Innovation

Integrating recent advances in innovation management and design theories with literature on private equity, we suggest variables for private equity models that better account for investors' roles in firms' regeneration processes. Following the three key steps – target selection, strategy, and valuation – depicted in the literature, such an investment mode would have the following characteristics and stakes, summarized in Figure 5 alongside the traditional investment models.

Target Selection: Not Only Creative Concepts or Predictable Growth, but also Innovation Capabilities

The regeneration capital model emphasizes U-products' key role. Scouting and selection processes need to be updated accordingly. The literature review shows that most current due diligence processes of mature firms do not include identification of U-products or firms' capabilities to develop and renew them.

Beyond identifying existing U-products, investors should also detect firms' organizational capabilities to sustain development and renewal. The innovation management literature suggests various approaches that help in this regard. Notably, an organizational function called the "innovation function" has been proposed (Börjesson *et al.*, 2014; O'Connor, 2008). This incorporates two main functions: managing an innovation portfolio and setting the firm's capability to systematically innovate. Some specific types of external partnerships can also be tracked (Cabanes, 2017; Le Masson *et al.*, 2010a).

In addition to reflecting regeneration capabilities, good indicators must deal with time constraints and restricted access to data, which investors often face during due diligence processes. One avenue for further research relates to how this model can also help interpret corporate VC, wherein financiers may have greater ability to identify U-products.

Valuation: Not Gut Feeling or Extrapolation of Past Performance, but Rather Concept Valuation

Investors need valuation approaches that will not only be based on pure extrapolation of past performance to avoid speculation. On the contrary, they must consider the future value and remaining design efforts linked to products still under development, as well as new U-product generation potential. These aspects are reflected in the premium valuation approach.

First, the premium incorporates two distinct scenarios regarding identified U-products. While a concept cannot be monetized per se, if there is sufficient maturity to generate a new head of lineage during the holding period, the related premium results from a quite-standard calculation. It supposes an evaluation of the turnover forecast with new products, but also of the spending that is necessary to develop from a partially unknown concept to a known lineage (*e.g.* salaries, cost of goods, costs of partnerships, CAPEX due to POC or pilots…). The issue then remains of how to value refinement of unknown concepts and related design efforts that would not result in the launch of a K-product during the holding period.

Then, investors who focus only on the expected value of U-products and neglect proper assessment and investment in related development costs are at risk of generating valuation bubbles by overestimating firm valuation and offering a higher price than with buyout or regeneration models. This raises the issue of expectation management (Le Masson *et al.*, 2013) and the risk of creating valuation bubbles by over-evaluating attractive promises. Venture capitalists already face such risks when counting on rising returns while incorrectly assessing or insufficiently supporting remaining design efforts. Refining the regeneration capital valuation model thus also addresses some of venture capitalists' concerns.

Finally, in real options, investors pay more in exchange for a right to postpone their decision based on learning accumulated in the meantime. Here, the premium embodies another role: it reflects what the investor is ready to pay to actively organize the regeneration process.

Strategy: Not Acceleration or Optimization, but Rather Concept Regeneration

Design-oriented investors not only provide additional financial resources to the invested-in firm, they also support its design strategy through both the generation of valuable new U-products and their development.

Investors need to develop post-investment strategies to support these U-products with two key variables: their involvement in the firm's strategic orientation and the interaction between activities related to U-products and historical ones. Regarding involvement in strategic orientation, some investors remain passive while others, as shareholders, actively back management. The latter are involved in the firm's governance and support U-products by guiding strategic discussions on non-monetary dimensions of post-investment strategies (*e.g.* networks to develop, research paths to explore). Investors each have their own resources to contribute to the remaining design effort, and related premium value differs from one co-designer investor to another. Regarding interactions between different types of activities, as mentioned in the literature review, the few studies on buyouts that do not focus on rationalization strategies depict a model of an entrepreneurship stimulator (Wright, *et al.*, 2001), (Bruining *et al.*, 2013), in which investors free up management to concentrate on innovation (Berg *et al.*, 2005). This is in line with the customary practice of operating a separate business plan and creating an innovation playground to isolate entrepreneurial activities, such as through labs or spinoffs. However, innovation management literature highlights the key role of interface mechanisms between major innovation management systems and the mainstream organization (*e.g.* interactions, knowledge reuse, networks) (O'Connor, 2008). Research on ambidexterity has also discussed balance, insulation, and interaction among exploration and exploitation activities, resulting either in incremental innovation or a more substantial renewal (Lenfle, 2008; March, 1991).

Another buyout strategy is increasingly used by practitioners: the buy-and-build, or build-up, strategy. This post-investment strategy consists of acquiring and combining several firms through additional buyout allowing for synergies to lead to value creation. Depending on the existence and nature of synergies, it can either enable U-product or K-product renewal.

Further Theoretical and Managerial Implications

The regeneration capital model discusses private equity segmentation according to a firm's life-cycle stages. A firm's life-cycle framework differentiates firms based on their age and size, ranging from newly created start-ups to aging big companies. This historical model tends to restrict the regeneration process to new firms and to hide the need for continuous innovation. Yet, over the long term, rationalization strategies usually implemented on mature firms through successive buyout investment cycles risk irreversibly damaging invested-in firms' innovation capabilities, as product obsolescence and external competition ultimately erode firms' financial performance and valuation. The regeneration capital model leads to another firm classification according to a firm's needs in terms of entrepreneurial activities. Besides, this approach offers a new way of

Figure 5 **– Models of private equity investments including the suggested regeneration capital model**

<table>
<tr><td></td><td>Seed capital</td><td>Late-stage venture capital</td><td>Buyout</td><td>Regeneration capital</td></tr>
<tr><td></td><td>Entrepreneurial innovation
Informal and non-predictive approaches</td><td>Concept development
Decision under uncertainty</td><td>Optimization
Formal valuation methods</td><td>Concept regeneration and development</td></tr>
<tr><td>Target selection</td><td>Very-early-stage firm, “informal” methods, ongoing research</td><td>Selection and scouting: young firms with high growth potential with an already defined creative concept and strong management team</td><td>Stable and mature firms with growth potential</td><td>Firms with innovation capabilities</td></tr>
<tr><td>Valuation</td><td>Small stakes, “gut feeling”, expertise-based but still intuitive valuation rationales</td><td>Convention-based approaches, market and income approaches</td><td>Theoretically: market and income approaches
Empirically: IRR and multiple of invested capital</td><td>Assess “U-products” value and development costs</td></tr>
<tr><td rowspan="2">Post-investment strategy</td><td colspan="2">Coaching
- Seed: diversified, mostly active investors
- Later-stage VC: faster commercialization
Resource provision (e.g. networks)
Innovation acceleration and lean start-up as adjustment techniques</td><td>Operational and financial engineering</td><td rowspan="2">Support “U-products” generation and foster realization</td></tr>
<tr><td>Monitoring: more-efficient non-predictive control strategies</td><td colspan="2">Monitoring: management compensation</td></tr>
</table>

structuring private equity. Instead of focusing on a firm’s life-cycle stage (creation, development, handover, decline), it highlights investors’ strategy and competences related to U-product or K-product support.

The key focus on U-products in the regeneration capital model suggests paying close attention to their identification from a managerial point of view. This would benefit from explicit concept formulation on the management side while, on the investors side, it requires an extension of tracking abilities and structuring of proper methods.

Additionally, the framework contributes to the study of private equity risks with regard to speculation and bubbles. It highlights the intrinsic risk of under- or over-valuating promises related to the next generation of innovations, which remain difficult to identify and characterize.

Conclusion

This research contributes to the VC and buyout literature that investigates the impact of private equity investment on firms' innovation capabilities. Building on recent advances in design theories, it complements private equity models with new dimensions; namely, the design of future potential products and their expected value. By proposing an original investment model that meets firms' need for support for repeated innovation, it initiates a renewal of private equity techniques in target selection, post-investment strategies, and valuation. The longitudinal case study validates the fact that this new model accounts much more effectively for certain investment strategies than classical models. It also confirms that a mismatch between a firm's design regime and the private equity fund mode of investment can, in the long run, hinder firms' innovation capabilities.

The exploratory study realizes a new model of regeneration capital that would benefit from further empirical case studies to refine its consequences and better characterize regeneration investors' rationales and tools. Indeed, middle-market firms present a diverse category. These firms are both described as mature firms generating sound revenues, owing to their existing activities, and entrepreneurial firms facing a need to maintain their competitive advantage by continually regenerating their activities. Thus, they must continually arbitrate on capital allocation between seed and development activities, which gives the investor two distinct roles: (1) buy an existing activity and typically optimize it, and (2) fund and support regeneration strategies. Thus, this firm category should, on the whole, benefit from a regeneration capital type of investment, and studying other firms could enhance the model's robustness. Furthermore, VC literature shows that the source of funds (*e.g.* bank, corporation, pension fund, government) and the market structure characteristics (bank-based or market-oriented) would influence the type of activity financed by private equity funds (Mayer, *et al.*, 2002). Therefore, additional interesting practices and refinement of our model could be extracted from analyzing deals for other private equity firms.

Finally, the regeneration capital model raises specific challenges, such as in managing a trade-off in financial and extra-financial resource allocation between regenerating the firm's activity and optimizing or scaling existing activity. There is also a methodological challenge related to U-product tracking by external investors facing time constraints and limited available data. Under specific conditions, the investor could take advantage of a patent analysis, but this cannot cover all cases; for example, it does not account for process regeneration. Other indicators could be tailored, such as prototypes, establishment of external collaborations, and networking. This remains a topic for further research.

Annex – Additional Methodology Insights

This annex aims at providing more details on the data collected for the NRJ case study.

Interviews

Interviewees	Date; duration	Type	Transcription
Senior and junior investors who concluded the deal	May 2016; 30 minutes	Semi-structured	Note-taking during the interview
Informal lunch	Early June 2016	Unstructured	Written summary after the interview
Senior and junior investors who concluded the deal	October 2016; 30 minutes	Semi-structured	Note-taking during the interview
NRJ financial director and chief executive	Late June 2016; 1 hour 30 minutes	Semi-structured	Recorded and transcribed

Interview guides were structured in four sections. In both cases, the first one consisted of an introduction of the interview and generic questions on the interviewees.

For the investors' interviews, the second part gathered questions on the fund's activities and organization. A third part focused on a general understanding of NRJ activities at the time of the transaction and its developments since then. The last part aimed at scrutinizing investment practices (investment thesis; sourcing, selection and valuation processes; post-investment strategy; transaction structure …).

The interview of the NRJ executive also included questions related to the firm's history. Then we investigated the firm development strategy with a focus on its innovation strategy. Finally, we discussed the capital structure and the various changes in capital ownership.

Written Documents

Three sources of written documents have been used in order to triangulate data.

Some files have been sent by the senior investor:

– Slides presented to the French private equity fund investment committee that decides whether or not to conclude the deal

– A strategic due diligence and an extended market and strategic review (conducted by two distinct external audit companies)

– Financial due diligence (conducted by an external audit company)

The following have been extracted from the fund's digital archives:

– A large number of legal and financial documents related to the deal (*e.g.* legal due diligence, shareholder agreement, incorporation documents, underwriting documents)

– A written document summing up the deal provided to the investment bank's board of directors

Public information has been collected on the Internet:

– The press release related to the closure

– 20 press articles related to the firm's founder, the deal, or the firm in general

– Patent data extracted from the online search tool Espacenet

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INVENTIONS AND SCIENTIFIC DISCOVERIES: IMPACT OF DESIGNERS' COLLABORATIONS ON CREATIVITY. AN ANALYSIS TOWARDS FIXATION EFFECTS

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ABSTRACT

Scientific discoveries and inventions have long been established as two distinct and sequential activities. It has nonetheless been showed that projects aiming at producing both scientific discoveries and inventions could record impressive results. Our investigations are focusing on the creativity of collaborations outputs: a first agent is entailed to design a scientific discovery and another one invention. We use fixation effects as a performance measurement indicator for creativity based on Design Theory. We propose a first set of elements that can be suffering from fixation effects in both invention and scientific models designers reasoning. We propose a series of defixed inputs that could be shared between both designers to overcome their fixation effects. We highlight that if partners are engaged in one-way knowledge transfer it can conduct to "fixation traps". We define a set of restrictive conditions that could conduct to a "cross-defixation process": both actors would be able to create conjoint new inventions and scientific models in the non-fixed design path. In particular this process does not required designers to be defixed before starting the collaboration.

Keywords: Innovation, Creativity, Human behaviour in design, Science, C-K design theory

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1 INTRODUCTION

Scientific discoveries and inventions have long been established as two distinct and sequential activities. As Vannevar Bush wrote in its report on science organisation in the United States *Science the Endless Frontiere* in 1945: "*The simplest and most effective way in which the Government can strengthen industrial research is to support basic research and to develop scientific talent*" (Bush, 1945). Science has to do with discoveries, and industry - with the help of engineering design - has to use science to create inventions. Nevertheless, the so-called "linear model" was challenged by many scholar's contributions (for example see Balconi *et al*. (2010) for a comprehensive literature review). In particular, Stroke's seminal contribution regarding the "Pasteur Quadrant" (Stokes, 1997) claimed that most of the famous scientists of all time have been motivated by both practical contributions (ie. inventions) and theoretical understanding (ie. discoveries) simultaneously. He found historical examples such as Pasteur, Keynes or the Manhattan project's research team. In a very recent study, Goldstein and Narayanamurti (2018) gave very clear insights regarding invention and discovery coupled dynamic. They studied the Department of Energy (DoE) in the United States between 2010 and 2015 which was organised around a sharp dividing line between a basic research department (ie. that has to do the scientific discoveries) and an applied research department (ie. that has to do the inventions). But in 2007 the DoE launched a new department called Advanced Research Projects Agency - Energy (ARPA-E) to finance projects that are at the interface between both departments: "*the aim of ARPA-E appears to be funding projects that are too technology-focused to be funded as basic research but are too novel to be funded as applied research*" (Goldstein and Narayanamurti, 2018, p. 1507). Authors showed that projects conducted through ARPA-E get impressive results: 57% of ARPA-E projects get either one patent (ie. invention) or one significant scientific publication (ie. discovery) while the average for other projects is only 27%. But then why not always conducting projects encompassing both fundamental research and inventions? As shown by Calvert (2006) in an international qualitative study, many scholars and policy makers consider that basic research is characterised by serendipity: unpredictability and generality of findings would be a driver for radical innovations. But in order to achieve those results, it has to be performed following a curiosity driven manner: "*Basic science produced plenty only so long as university researchers were left alone, unhampered by demand for short-term results or particular products*" (Slaughter, 1993, pp. 284–285). And organisation that clearly separate those activities can record high performances in terms of science and inventions. For example the largest Public Research Organisation (PRO) in France, the Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA), is still organised with two distinct department regarding fundamental research ("CEA Science" and inventions ("CEA Tech"). In 2017, first, CEA Sciences recorded similar scientific publication performances than the MIT or Max Planck organisations. Second, CEA Tech, with six time less employees than Fraunhofer Geselshaft, filled 608 patents which is almost the same number of patents than the German PRO (Comptes, 2018).

In this apparently inconclusive debate we focused our investigations on a particular aspect of scientific and invention collaboration performances: the capacity to provide new scientific models and inventions that are "creative" or "original". This is an important stake as we can assume that it could be a starting point for radical innovations, even if it has to be coupled with additional factors such as business model, consumers' attempts, marketing, etc. There are many contributions in engineering design regarding creativity and originality when designing a particular artefact. Literature is nevertheless scare from our understanding regarding science. As performance indicator, we use the concept of fixation effects. It illustrates a situation in which a designer is locked-in in a specific design path and is not able to propose other significantly different solutions. Those not reached solutions are then call "creative" or "original". **The research questions are then the following: in science - industry collaboration, how could the scientific partner help the industrial one to overcome its fixations effects regarding the design of an invention? Reciprocally, how could the industrial partner help the scientific one to overcome its fixations effects regarding the design of a scientific discovery?**

To reach this goal it is necessary to draw on a unified model of invention and scientific discoveries that helps to highlight those fixation effects. Design Theories have been helpful to model inventions which is a core historical objective in Design Theories. It has also been showed recently that Design Theories are a powerful resource to model scientific discoveries. In particular C-K theory is a unified model of Design Theories that (1) allows us to model both invention and scientific discoveries, (2) has been previously showed as a key resource to model fixation effects (Agogué and Le Masson, 2014), and (3) has been previously showed as a useful theoretical framework to model partnership effects (Gillier, Kazakçı and Piat, 2012), in particular regarding science - industry partnership (Klasing Chen *et al.*, 2017). We then first briefly recall to reader C-K theory basic reasoning and we propose a model of invention and scientific discoveries according to this framework. Second, we draw on those models to show what fixation effects designers of inventions and scientific models can suffer from and what resources available help them to overcome those fixations. Third, we present a dynamic model of interactions between both designers to highlight conditions under which actors are able to overcome their fixations.

2 A MODEL OF SCIENCE AND INVENTION REASONNING THROUGH DESIGN THEORIES: HIGHLIGHTS OF FIXATION EFFECTS

2.1 C-K Design Theory and fixations effects

C-K Design Theory aims at providing a unified and rigorous framework for design and has been initially developed by Hatchuel and Weil (2003, 2009). In particular, its ability to describe the generation of new objects and new knowledge has been highlighted both in academic literature and following industrial use. The theory is based on the interplay between two distinct but interdependent spaces. First, the knowledge space (K) contains all propositions with a logical status (ie. true or false) regarding available knowledge that a designer is able to draw on to perform its design activity. Second, the concept space (C) contains all propositions regarding outputs or objects set up by the designer but neither true nor false according to the state of the designer's knowledge. Indeed, when designers are faced with concepts, they cannot affirm whether such a thing may be possible or not. Those concepts are the partially unknown outputs or objects. Those propositions are qualified as "undecidable" relative to the content of the knowledge space (K) if it is not possible to prove that these are true of false. The C-space has a tree structure and each node represents a partition in sub-concepts. Furthermore, during the design process, both concept and knowledge spaces are expandable following four possible transformations: C➔K (ie. conjunction); K➔C (ie. disjunction); C➔C (ie. partitions) and K➔K. In particular, the design process attempts to define a conjunction: to transform an "undecidable" proposition in the concept space into a logical proposition in the knowledge space.

C-K theory has allowed further theoretical development regarding fixation effects. Indeed, as the theory helps to represent different design path, it has been used to show how a designer could be locked-in in a specific design path and then not able to explore more innovative path without being "defixed" (Agogué, 2012; Agogué *et al.*, 2014). In particular, the literature in management identified some innovations pathways do not seem achievable for a specific firm due to lack of knowledge, lack of absorptive capacity or its own historical pathway depending on its starting point and hazardous events (Sydow, Schreyögg and Koch, 2009). Kaplan and Tripsas (2008) introduced the notion of "cognitive path dependence" by showing how actors select ideas within a collective cognitive framework around a dominant technological trajectory. Thrane *et al*. (2010) then highlighted how collective cognitive framework can lead to constrain the exploration of alternatives. In particular, some fixation effects occur at a cognitive level due to the fact that people tend to generate ideas the most accessible in memory which might le ad to fixation effects (Hatchuel, Le Masson and Weil, 2011). Agogué and Le Masson (2014) distinguish two forms of ideation reasoning. The first is a **fixated reasoning** based on the use of cognitive routines calling for existing solutions with stable paradigms. It tends to maintain already existing solutions and favour incremental innovation. If a whole innovation team involved in an ideation process adopted those reasoning - which is likely to be the case in a same organisation due to common constraints – incremental outcomes will not be challenged. The second is a more **explorative reasoning** that lead to propose more creative and disruptive ideas through a controlled exploration of alternatives. In particular it has been shown with simple tasks how fixation effects constrain creativity and how examples outside the fixed design-path help actors to stimulate their creativity through expansive concepts (Agogué, 2012; Camarda *et al*., 2017).

2.2 Modelling invention through Design Theory

Invention is the "*accumulation and creation of knowledge that results in a new tool, device, or process that accomplishes a specific purpose*" (Narayanamurti, Odumosu and Vinsel, 2017, pp. 31–32).

To simplify our model we consider inventions only as patentable ones. This help us to draw on the literature in engineering design regarding what are the core criteria associated with invention. We acknowledge that there is a debate regarding originality of patent inventions and that it might exist high or law quality patents (cf. patent rating issues). Nevertheless, as we are focusing on creativity and originality of inventions the C-K theory will help us to classify inventions regarding design paths.

Drawing on C-K formalism, Sincholle (2009) and Le Masson *et al*. (2014) defined patents in an "Action - Effect - Knowledge" model in order to avoid an approach only based on legal and intellectual property. They proposed a patent content taxonomy comprising of three elements. **Action** is defined as the solution brought by the invention (ie. intervention made on objects). **Effects** comprise of the action's effects on specific objects (ie. consequences brought by the action). **Knowledge** comprise of initial state of the art (K_0) and the results of the new action or effect. This model highlights a first patentability criteria: novelty. It is described by the following elements :*"(1) An invention shall be considered to be new if it does not form part of the state of the art. (2) The state of the art shall be held to comprise everything made available to the public by means of a written or oral description, by use, or in any other way, before the date of filing of the European patent application*" (art. 54 of the European Patent Convention). According to the model, it verifies the following formalism: $(A_1, \dots, A_n \rightarrow E_1, \dots, E_n) \not\subset K_0$. This model help us to define another key patentability criteria: the inventive step. "*An invention shall be considered as involving an inventive step if, having regard to the state of the art, it is not obvious to a person skilled in the art*" (art. 56 of the European Patent Convention). For example, if the person skilled in the art is capable to pose a similar problem than the one in the patent application, to solve it similarly to the proposed invention and to predict the results: the inventive step is not valid. It means that inventions cannot be the result of a new combination of already existing knowledge that the person skilled in the art (PSA) could have done (Le Masson, Weil and Hatchuel, 2014), then formally: $(A \rightarrow E) \not\subset PSA(K_0)$. In particular, the "C-K invent" method (Felk *et al.*, 2011; Kokshagina *et al.*, 2014) highlights that the inventive step can be modelled through an expansive partition, not related to $PSA(K_0)$, that expands the concept space. This expansive partition: "*significantly modify or propose new actions and effects to generate new sentences - new ideas for patent proposals*" (Kokshagina *et al.*, 2014, p. 405).

Based on this brief literature review, we can formulate the following assumptions regarding the design of an invention, understood as a patentable one:

- **Assumption 1.1 - state of the art knowledge acquisition:** a designer has to acquire a significant knowledge base relevant to its invention field (including a comprehensive state of the art comprising all available public data) in order to both design its invention and guarantee its novelty.
- **Assumption 1.2 - expansive partition**: a designer has to create a concept that is a new expansive partition not related to $PSA(K_0)$. The invention will be the result of a conjunction (ie. the new concept become true according to the designer's knowledge base).

2.3 Modelling science through Design Theory

Discoveries are "*creation of new knowledge and facts about the world*" (Narayanamurti, Odumosu and Vinsel, 2017, p. 32). Hatchuel *et al*. (2013) proposed a formalism of scientific discoveries through Design theories. According to the authors, discoveries are based on a scientific method which requires a logic of modelling and the core of the scientific conversation is then to focus on the consistency, validity, testability of models and to make advancement regarding how models are fitting with existing or experimentally provoked observations. They established the following assumptions:

- **Observability:** the object of scientific modelling X_i is observable through observations x_i and it is assumed that observing those x_i do not provoke the existence of X_i ;
- **Consistency & completeness:** scientific models can be express through a consistency function (ie. defining the quality of the scientific reasoning such as no contradiction, no redundancy, etc.) and a completeness function (ie. quality of the relationship between the model's predictions and observations x_i).
- **Anomaly existence:** the model aims to reduce two types of knowledge anomalies: (1) a lack in the consistency function or (2) an apparition of new observations Y (directly observable or provoked) that are not predicted by the model.
- **Not yet observable unknown object existence:** facing anomalies, scientist make the hypothesis that there may be an unknown object X' observable but not yet observed. The aim of the scientific

process is either to elaborate $K(X')$ that would provide a definition of X' and validate its expected properties or to get more observations x' to confirm the existence of X'.

By drawing on this model, we can formulate the following assumptions regarding the design of a scientific discovery:

- **Assumption 2.1 - knowledge acquisition:** a designer has to acquire a significant knowledge base regarding existing scientific models relevant in its discovery field. Indeed, the designer has to be capable of (1) identifying an anomaly regarding previous scientific models and (2) elaborating new models or improving consistency and completeness functions of previous models.
- **Assumption 2.2 - expansive partition**: a designer has to provoke an expansive partition regarding its C-space according to two strategies to make a discovery:
  - Assumption 2.2.a: a designer could improve consistency and completeness functions of previous scientific models and provoke new expansive partitions regarding those models;
  - Assumption 2.2.b: a designer could propose new scientific models which would be expressed through new expansive partitions.

3 SCIENCE & INDUSTRY FIXATIONS: DEFINITION, ORIGINS AND MITIGATION STRATEGIES

3.1 Objects of science and industry fixations and main influential factors

Scientific discoveries and inventions designers are suffering from a couple of fixations effects. We first define what elements of the design process are suffering from those effects. Second we define what would be the main factors that sustain those fixations. By drawing on the definition of scientific modelling and invention below, the object of fixations are the following:

Table 1. Science & invention elements of reasoning that could be the object for fixations

Science	Invention
• Object of scientific modelling (ie. studied dimension of an object); • Scientific hypotheses (ie. consistency and completeness functions); • Methodologies and scientific equipment & tools (ie. observations methods); • Anomaly detection and interpretation (ie. observations and comparison with previous scientific models); • Results and findings (ie. designed concepts).	• Technological paradigm (mastered technologies and technology combinations) to produce action and effects); • Relevant scientific models of those technological paradigm (associated knowledge); • Artefact type that is produced by the industry and its competitors (and associated production process).

We then propose a taxonomy of factors that increase fixation effects through the adoption of fixed reasoning. Those factors can conduct scientific model and invention designers to stay in less creative design paths. Organisations can try to work on those factors to favour defixation processes.

Table 2. Factors that strengthen designers' fixation effects

	Science	Industry
Economic factors	Economic incentives that researchers received to stay in non-creative design path to maximise their probability to publish high-ranked scientific journal articles (eg. rewards based on scientific journal ranking).	Economic incentives that inventors received regarding working on artefacts in core technological paradigm of the company (eg. reward based on the acceptance of the company to finance a patent filling procedure - which is not likely to be the case if the invention is not part of the strategic plan of the company).
Social factors	Social incentives to stay in fixed design path regarding peer	Social incentives to stay in fixed design path regarding peer

	recognition and acceptance in laboratories, particular scientific discipline or groups.	recognition and acceptance in other invention designer social groups in the industry or in the organisation.
Organisational factors	Orientation given by science programmes, funding, grants and strategic priorities regarding fixed design paths.	Orientation and funding given by R&D department or strategic priorities given by management (following for example previous company investments).
Individual	Use of cognitive routines calling for existing solution with stable paradigms in designer process.	

3.2 Mitigation of fixation effects through science-industry interactions

As shown in Agogué and Le Masson (2014) works, examples outside the fixed design path help designers to propose more creative solutions. In science-industry partnerships, invention and scientific model designers would be able to exchange defixated inputs. Following the linear model logic, it is well documented how a scientist could bring defixated inputs to invention designer through new fundamental discoveries that lead new inventions (eg. the Manhattan project has been extensively used as a core example[1]). As a more recent case, graphene synthetisation discovery in 2004 by A. Greim is illustrative (Nobel Prize 2010). Indeed, following his fundamental discovery of new carbon forms as a new material, a couple of industries are reviewing potential applications such as new transistor generation. Nevertheless, the phenomenon is less documented regarding what defixed examples industrial can bring to scientific model designer. We propose the following list of inputs and associated probabilities (“prob.”) regarding historical examples.

Table 3. Defixating inputs of invention’s designer to scientific discovery’s designer

Fixation issue	Prob.	Details	Example
Object of scientific modelling	Medium	New industrial stakes for companies that lead to study other dimensions of an existing object; New object created by industry.	Bipolar-contact transistor invented in Bell labs by Shockley, Bardeen and Brattain that conduct to new scientific discoveries regarding its effects.
Methodologies and scientific equipment & tools	Medium	- New scientific tools created by the industry to detect new observations.	The quantum computing developed by major IT companies and its effects on calculation possibilities for physics analyses.
Anomaly detection and interpretation	High	Industrial issues that require scientific advances to be solved.	Pasteur and the invention of the microbiology following its intervention with North of France brewers (cf. also case study on CRISPR in section 4.3)
Results and findings	Low	New results due to large scale testing centres of the industry or real condition testing.	Higgs’ Boson and new scientific knowledge due to the testing of its theory in LHC.

4 DYNAMIC ANALYSIS OF SCIENCE-INDUSTRY INTERACTIONS: FIXATIONS TRAPS & CROSS-DEFIXATION PROCESSES

In order to define science-industry implications on the exploration of more creative design paths we are drawing on the “matching-building” model developed by Gillier *et al.* (2012). The latter is useful to demonstrate effects of partnerships on knowledge and concept bases of each actor. We then call “Agent A” the designer of the new invention and “Agent B” the designer of the new scientific model. We assume that at the beginning of the partnership, both actors are fixed in their own specific design path.

[1] On this topic, see Lenfle (2011) for further discussions

4.1 Matching phase

In the matching phase, actors involved in the partnership investigate together their own C-K frame to identify intersections. If actors are sharing similar concepts or knowledge need, they can engage common exploration or knowledge transfer in order to provoke partitions and new conjunctions.

Regarding new inventions and scientific models designers, if there is a match between their concepts or knowledge need (1) at least one expansive partition has already been carried out by agent A and/or agent B and (2) those expansive partitions occurred in the fixed path. Two particular cases can be highlighted. The first is referring to the "Mode 2 knowledge production" (Gibbons *et al.*, 1994): agent B is able to provide to agent A the required knowledge to help the latter to provoke a conjunction in its C-K frame which constitute a new invention. It is describing the classical model of research commercialisation. For example an industrial asks a research team to solve a particular problem taking in account all its industrial constraints such as past investments, consumer needs, etc. The second is referring to "reverse mode 2": agent A is able to provide to agent B the required knowledge to help the latter to provoke a conjunction in its C-K frame. It is referring to a situation in which for example the industrial partner is able to bring an invention to help to scientific model validation (Narayanamurti, Odumosu and Vinsel, 2017). It has to be noted that the actor that is transferring knowledge also learns from the process and then can be able to provoke new partitions in its C-space: new inventions and scientific models then appear in a sequential model.

Regarding fixation effects in those cases, it has to be noted that the initial partition is associated to the fixed design path, as well as the conjunction following the partnership. Nevertheless the party that provide the knowledge and learn from the exchange process could be able to access to defixating inputs from the other partner (see section 3.2). The probability remains low because those cases mainly describe one-way transfer. Indeed, the partner that initially ask for knowledge transfer does not need to extensively share its own knowledge except for very detailed specifications limited to the adaptation of what is being transferred. Worse, it can give fixed examples that will strengthen fixation effects. If new inventions and new scientific models occurs, (1) it is highly probable that both outputs are linked to fixed design path and (2) occur in a sequential modes. We then call those situations "fixation traps".

4.2 Building phase

The building phase occurs when actors do not find relevant intersection between their different C-K frames. It means that (1) they do not have many interaction between their knowledge base and (2) they are committed to define both new inventions and new scientific models: actors need to "build" a shared and relevant concept between them. In that phase, partners are collecting in a first time information about each other which is "*an opportunity for partners not only to expand their concept and knowledge spaces but, more interestingly, to revisit them*" (Gillier, Kazakçı and Piat, 2012, p. 386). In a second time, interactions between both actors will conduct them to "*imagine a more abstract concept that could interest all of them*" (Gillier, Kazakçı and Piat, 2012, p. 386) that can lead to highly expansive partitions. For agent A and B we interpret this bi-directional exchange of knowledge as a factor that increase the probability of sharing a defixated input such as new dimensions of an object for scientific modelling. The engagement of agent B to favour agent A's new inventions also helps to recognize anomalies regarding previous scientific model following phenomenon reported by agent A. Second, the fact that both actors have to imagine a more abstract concept in particular help agent A to being defixed regarding traditional industry constraints and be more open to more creative design path.

We have to notice that under a set of conditions that drive this building phase, agents A & B are able to engage in what we call a "**cross-defixation process": both partners are able to share an abstract concept and to then acquire and exchange new knowledge to favour conjunctions in non-fixed design path**. The particularity of this cross-defixation process is that it conducts both actors to generate creative output but in a conjoint mode. We propose a synthesis vision of the required conditions:

- **Condition 1**: Agents A & B do not share pre-existing concepts (or at least are not entailed to work on them) - this condition is referring to the building stage;
- **Condition 2**: Agents A & B have a significant knowledge base relevant to their field of activities that support their capacity to provoke partitions - this condition is referring to the capacity to bring novelty and new scientific models;

- **Condition 3**: There is limited intersection between agents A & B knowledge base - this is a condition referring to building stage (if not we assume that they would be able to match some concepts);
- **Condition 4**: Agents A & B are ready to both (1) reassess their own knowledge bases and (2) favour bi-direction knowledge exchange in order to find a shared area of interest - this condition is referring to the capacity of both actors to overcome fixation effects.
- **Condition 5**: Agents A & B are highly committed to both obtain a very practical answer to the invention designer and a model with high consistency and completeness standard for the scientific discovery designer - this condition is referring to overcome anomaly detection and interpretation fixation effects.

4.3 Case study: CRISPR & Danisco company - a case of cross-defixation

In this section we illustrated our results through a brief recent case study on CRISPR-Cas9, a fundamental discovery in genome editing[2]. Based on cross-checked sources regarding CRISPR[3], we are focusing here on the contribution of an agri-food industrial company called Danisco.

In its business unit of Dangé-Saint-Romain (France), Danisco was producing bacterial starter cultures for cheeses and yogurts production. In 2004-2005, the company launched an R&D project focusing on a particular lactic-acid bacteria (*Streptococcus thermophilus*). The latter was intensively used in the production process but were sometime attacked by viruses (ie. bacterial phage) with high financial implications for the company. More surprising, when attacked by phage, Danisco showed that some bacteria were able to protect themselves against the viruses while some other died. The R&D project's goals were then (1) to better understand this phenomena and (2) to propose new industrial processes to favour bacteria survival. To perform this project, the company appointed P. Horvath as team leader, an experienced scientist specialized in microbiology and acid lactic DNA.

We reinterpreted this case by using the framework described in the upper section. Agent A is represented by Danisco who aim to design a new industrial process to favour bacteria preservation. Agent B is represented by the research team who aim to design a new scientific discovery regarding this phenomena. Both designers have acquired a significant knowledge base in their respective domains. Indeed, for Agent A, bacterial starter culture is the core industrial process (the company at Dangé-Saint-Romain was established in 1964 already on this market). For Agent B, P. Horvath got his Ph.D. from Strasbourg University where he was focusing on genetics of lactic-acid bacteria for food production (Condition 2). Nevertheless, their knowledge base remain distinct for the project as P. Horvath was appointed for its expertise on acid lactic DNA following the acquisition by Danisco of a DNA sequencer (Condition 3).

Regarding the matching - building model, agent A and B do not share pre-existing concepts regarding this topic as they were not able to transfer available piece of knowledge to directly solve the issue (Condition 1). P. Horvath's team was able to reinterpret the industrial issue as a scientific anomaly: how some micro-organisms, such as a bacteria, could be able to protect themselves from virus phage while their pairs do not? Indeed, according to available scientific models at that time, bacteria strains cannot protect themselves without having similar responses to phage. Due to this anomaly, both designers were able to reassess their knowledge to overcome their fixation effects. Facing the anomaly P. Horvath's team were able to identify Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) when genotyping cell strains, a concept that he heard about in a scientific conference a few years ago. Having access to 10,000 acid lactic bacteria strains used in the company and Danisco expertise in that domain (Condition 4), they were able to demonstrate a correlation between presence of CRISPR in the genotypes of cell strains and resistance to phage (ie. it broadly act as a 'vaccine' but at a micro-organism level). They were the first research team to demonstrate this correlation by using empirical analyses. Furthermore, due to their commitment to provide both scientific and industrial response to this issue (Condition 5), the research team developed an industrial process to add phage DNA to acid-lactic bacteria in order to favour their resistance to

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[2] The scientific discovery is mainly attributed to J. Doudna and E. Charpentier for their article in *Science* (Jinek et al., 2012)

[3] Main references includes: Lander works on scholars that made CRISPR (2015) ; Report for the French Senate from Le Deaut and Procaccia (2017) and *Le Monde* special focus on CRISPR (2016)

viruses. They patented their invention (final application in 2006 at the USPTO) and the associated scientific article was published in *Science* in 2007. This project led to a cross-defixation process for both invention and scientific model and all the five conditions of our framework were valid.

5 IMPLICATION AND FURTHER RESEARCH

Our main objective was to understand under which conditions new invention and scientific model designers were able to partner in order to produce better creative and original outputs. We drew on C-K theory and focused on fixation effects in order to interpret in which situations designers are able to provide outputs whether on a fixed design path or in an original path. We showed how design theories modelled both patentable inventions and scientific models that offered us a coherent and unified framework to deal with those issues. Our contributions are the following. (1) We proposed a first set of elements that can be suffering from fixation effects in both invention and scientific models designers reasoning and briefly explained what the main contributing factors are. (2) As examples in the defixed design path can help designers to propose new inventive solutions we propose a series of defixed inputs that could be shared between invention and scientific designers to help them to overcome their own fixation effects. We also provided a couple of historical examples. (3) We then used the matching - building model to define the effect of invention and scientific model designers' partnerships on fixations. We showed that if partners are engaged in one-way knowledge transfer, those partnerships can conduct to "fixation traps": inventions and scientific models are sequential and linked to the fixed design path. (4) We defined a set of restrictive conditions that could conduct to a "cross-defixation process": both actors would be then able to create conjoint new invention and scientific model in the defixed design path.

Our findings seem consistent with current debates regarding science organisation. Indeed, "cross-defixation" processes advocate for strengthening partnerships between science and industry. A particular issue is that the parties do not necessary need to be "defixed" before starting the partnership: by setting particular conditions regarding the partnership design, both initially fixed designers might be able to provide original and creative outputs. The success conditions also led to highlight the importance of designer educations to detect what would be those defixated inputs and how to share them in the most efficient way. Furthermore, there is a need to conduct further analysis regarding those conditions and how it match with firms strategies (in particular regarding intellectual property stakes and strategies regarding the exchange of those defixated inputs). Further analysis have also to be carried out regarding associated management practices. Nevertheless, we shed light on a particular situation that conduct to "fixation traps": in those, as it is mainly a one-way exchange of knowledge, the probability that designers shared defixing example is low, and it can even strengthen fixation effects. We acknowledge that knowledge transfer between science and industry is key for national innovation system. But first, partners have to be aware of what they have to attempt from those partnerships in terms of creative outputs and those have to be aligned with management practices. Second, it would be easier for an organisation to define fixation effect mitigation procedures outside those kind of partnership in order to produce creative outputs. We think that focusing on fixation effects on science and industry collaborations could help scholars and practitioners to foster specific collaborations or framework success conditions (eg. collaborative PhD as the "CIFRE" scheme in France). In particular, further qualitative and quantitative research are necessary to confirm the model's insights.

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Axe 3 : Théorie de la conception et neurocognition de la créativité

1) Ezzat, H., Agogué, M., Le Masson, P., Weil, B. and Cassotti, M. (2018). Specificity and Abstraction of Examples: Opposite Effects on Fixation for Creative Ideation. *The Journal of Creative Behavior*, Wiley, 2018

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Specificity and Abstraction of Examples: Opposite Effects on Fixation for Creative Ideation

ABSTRACT

Fixation is one of the major obstacles that individuals face in creative idea generation contexts. Several studies have shown that individuals unintentionally tend to fixate to the examples they are shown in a creative ideation task, even when instructed to avoid them. Most of these studies used examples formulated with high level of specificity. However, no study has examined individuals' creative performance under an instruction to diverge from given examples, when these examples are formulated with a high level of abstraction. In the present study, we show that (a) instructing participants to avoid using common examples when formulated with a high level of specificity increases fixation; whereas (b) instructing participants to avoid such examples while using a more abstract level for stating these common examples—such as a categorization of these examples—mitigates fixation and doubles the number of creative ideas generated. These findings give new insights on the key role of categorization in creative ideation contexts.

Keywords: fixation effect, idea generation, examples, categorization.

Creativity has been described as the capacity to generate ideas that are both novel and useful (Amabile, 1996), and constitutes one of the key cognitive skills that individuals use daily in various contexts. According to divergent thinking scholars (Guilford, 1959), creative individuals usually exhibit high levels of ideational fluency, flexibility, and originality (Runco & Acar, 2012). However, the process of creative ideation is not always an easy task, and could be spontaneously and intuitively constrained by previously acquired knowledge, by individuals' own mental models or even by earlier ideas generated. Indeed, several studies have shown that these various factors could constrain one's cognitive ability to generate novel and creative ideas (Agogué, Kazakçi, et al., 2014; Jansson & Smith, 1991; Smith, Ward & Schumacher, 1993). Psychologists have labeled this phenomenon as fixation (Cassotti, Agogué, Camarda, Houdé & Borst, 2016; Jansson & Smith, 1991), aka the blind mental adherence to a set of ideas (Cassotti, Camarda, Poirel, Houdé & Agogué, 2016).

One classical task to illustrate fixation is called the "two cords problem" of Norman Maier (Maier, 1931). Two cords (tied to the ceiling) and pair of pliers were provided to participants, who were asked to tie together the free ends of these two cords. In this experiment, most participants were fixated on the knowledge they had of pliers, and were unable to look at it alternatively by simply tying the pliers to one of the cords to form a pendulum that will swing to reach the second one. In fact, the accumulated knowledge about the typical use of pliers was spontaneously activated in individuals mind, and prevented them from seeing alternative uses (Maier, 1931), and thus impending creative thinking. Such effect, characterized in this case in a problem-solving situation, has been demonstrated to occur as well in more openly framed problems, where participants need to generate a lot of different ideas to a specific situation (Agogué, Poirel, Pineau, Houdé & Cassotti, 2014).

More specifically, multiple experimental psychology studies have showed that previously acquired knowledge in individuals' mind is most likely to act as a mental set promoting fixation (Adamson, 1952; Sio, Kotovsky & Cagan, 2015). Moreover, other studies related to the role of examples on creativity have shown indeed that exposure to examples could play either a positive or negative role to modulate fixation. Smith and colleagues demonstrated that designers unintentionally tend to conform to the features of the example they were shown (Smith et al., 1993). In three experiments using a creative ideation paradigm in which subjects had to imagine and sketch new exemplars of experimenter-defined categories, the authors showed that individuals surprisingly replicate the features of the example even when they are explicitly asked to propose ideas that are different from the given example.

Deepening our understanding of the role-specific examples may play in creative thinking, Agogué and colleagues showed that two types of examples could actually have opposite effects on fixation modulation (Agogué, Kazakçi, et al., 2014). In a creative ideation task where participants had to generate creative ideas to ensure that a hen's egg dropped from a height of ten meters does not break, the authors experimentally demonstrated that participants exposed to a common example (within the fixation) increased the number of solutions within the fixation; whereas participants exposed to a creative example (outside the fixation) decreased the number of solutions within the fixation, and consequently increased originality of solutions.

Focusing on the way instructions to be creative are delivered to participants, other studies have provided discrepant results regarding the role of warnings and constraints on fixation modulation. Chrysikou and Weisberg (2005) showed that the fixation effect can be reduced using instructions which warn subjects about the use of the flaws of an example (Chrysikou & Weisberg, 2005). On the contrary, Viswanathan and Linsey (2013) confirmed Smith and colleagues' findings (1993), and demonstrated that even when designers are presented with warnings about the undesirable example features along with the reasons for those warnings, fixation to those features is not mitigated (Viswanathan & Linsey, 2013). These discrepant results could let one think at first glance that there could be a certain relationship between the level of abstraction of the examples and the level of fixation mitigation. In fact, these findings may suggest that the more the constraints and warnings on examples are abstract (without clear indications about the features of the examples), the more fixation would be mitigated. Similarly, one could also think that the more constraints on examples are specific (with clear specification of the features of the examples), the more fixation would be reinforced.

In consistency with this role of specificity and abstraction on fixation modulation in creative ideation, Baughman and Mumford (1995) demonstrated that when people are asked to combine exemplars from separate categories to form a single inclusive category, which is considered an act of categorization, participants become more original (Baughman & Mumford, 1995). These results provided interesting indications about the role of abstraction for fixation mitigation and the generation of creative ideas. Moreover, Ward and colleagues (Ward, Patterson & Sifonis, 2004) confirmed these findings on the role of abstraction for creativity. In their classical experiments where participants were asked to imagine life on other planets, the authors demonstrated that instructions encouraging participants to formulate the given task in more abstract ways led to more creativity than instructions encouraging participants to formulate the task in very specific ways. However, the influence of the level of abstraction on creativity has been only solely explored through the perspective of the task formulation. More focus could be placed on the relationship between the level of specificity and abstraction, and the level of fixation mitigation by applying it to the use of examples.

To assess this relationship between the level of abstraction and fixation mitigation—and in line with the abovementioned findings—the aim of the present study was to examine the effects of instructions warning about using either common examples formulated with a high level of specificity, or more abstract levels of these same examples. To achieve this aim, participants were asked to solve a creative task (i.e., the hen's egg task) and were provided with instructions warning about using common examples—either at a high level of specificity or at a more abstract level—at the beginning of the task. We reasoned that if the influence of examples on creative ideation depends on the level of abstraction, then instructing individuals to avoid using common examples—at a high level of specificity—should reinforce fixation; whereas instructing individuals to avoid using common examples—by framing those examples at a more abstract level, such as a categorization of these examples—should mitigate fixation.

METHOD

PARTICIPANTS

Seventy-five participants of an introductory course of innovation design were recruited for this study. To ensure that the content of the course had no influence on the performance of the participants, the experiment was made at the very beginning of the course. Participants were engineering students and professionals (91% of the subjects were engineering students, while 9% were professionals). Participants (69% men) were between 19 and 58 years old (*M* = 25.6 years, *SD* = 6.9). Participants were randomly assigned to one of the three experimental groups: a control group without constraints (*n* = 25, *M* = 24.84 years, *SD* = 5.51, 18 men), a group "Specific" with constraints on examples (n = 25, M = 25.72 years, SD = 5.95, 20 men) and a group "Abstract" with constraints on categories of examples (n = 25, M = 26.36, SD = 9, 14 men). ANOVA and chi-squared analyses indicated that the mean ages ($F(2, 72) < 1$) and gender distributions ($\chi^2 = 3.51$, $p = .17$) did not differ significantly between the groups. Sample size was determined pre-hoc by running an a priori power analysis using G*Power 3.1.9.2 (Faul, Erdfelder, Buchner & Lang, 2009), revealing that a minimum of 66 participants would be needed to detect a medium effect size of 0.20 (according to Cohen's effect size conventions), with a power (1-β) set at .80 and an α set at .05."

DESIGN AND PROCEDURE

Each participant was given 10 minutes to perform individually a creativity task where the aim was to propose the maximum number of original solutions to "ensure that a hen's egg dropped from a height of ten meters does not break". Individuals had to write down on a sheet of paper all the solutions they could come up with, and were prohibited to talk with each other. Not only the hen's egg task could be the appropriate creativity task to select since it does not require specific knowledge and expertise from the participants, but as we have mentioned earlier, previous studies of Agogué and colleagues (Agogué, Kazakçi, et al., 2014) used Concept-Knowledge theory (Hatchuel & Weil, 2002), to build a cartography of solutions of the hen's egg task, distinguishing between solutions labeled fixation (common or less novel ideas based on the most accessible knowledge) and solutions labeled expansion (rare or more novel ideas based on less accessible knowledge outside fixation). In fact, over the past 5 years, the authors demonstrated that 81% of the solutions generated by participants to this task were fixated around three categories of solutions (which are "damping the shock", "protecting the egg", and "slowing the fall"). These three categories were considered to be inside fixation. However, only 19% of the solutions were outside fixation (for instance: "before and after the fall", "with a living device", "using intrinsic properties of the environment", etc...). This database comprises a total of 716 proposed solutions from 122 students (from the Faculty of Psychology of Paris Descartes University) who performed the hen's egg task in two previous studies (Agogué, Kazakçi, et al., 2014; Agogué, Poirel, et al., 2014), and is updated regularly with new solutions and categories of solutions if participants come up with new solutions that do not fit with the current categories. Table 1 shows a list of the range of categories of solutions of the hen's egg task. We used these works to delimitate the frontier between what is inside fixation (simply labeled "fixation" according to these studies) and outside fixation (labeled "expansion" according to these studies), and therefore identify the common examples (inside fixation) for this creativity task.

TABLE 1. Categories of Solutions of the Egg's Task (Agogué, Kazakçi, et al., 2014)

Categories of Examples	Example of Solutions	Fixation/Expansion (ideas that are not fixation)
Damping the shock	Place a mattress at the reception	Fixation
Protecting the egg	Pack the egg with bubble wrap	Fixation
Slowing the fall	Hang the egg to a parachute	Fixation
Interrupting the fall	Catch the egg with a net	Expansion
Acting before the fall	Drop the egg at a height of 11 m	Expansion
Acting after the fall	Replace the broken egg with an unbroken one	Expansion
Using a living device	Train an eagle to take down the egg	Expansion
Modifying the properties of the egg	Freezing the egg	Expansion
Using the natural properties of the egg	Drop the egg on its most robust axis	Expansion
Using the properties of the environment	Drop the egg at zero gravity	Expansion

Participants were randomly assigned to one of the three groups. All participants were provided with the typical instruction of the hen's egg task: "You are a designer and your manager gives you the following problem: Ensure that a hen's egg dropped from a height of 10 m does not break".

The control group was provided with an additional guideline stating that: "The evaluation of your manager will be based on the number of original ideas you will propose".

Participants of the group "Specific" were provided with another additional guideline, imposing constraints on specific examples inside fixation. The guideline stated that: "The evaluation of your manager will be based on the number of original ideas you will propose, knowing that your solutions must not use mattress, nor parachute, nor bubble wrap". These three specific examples were precisely chosen among others, due to the fact that they were the most generated examples in each of the three categories of fixation in an existing database of participants that performed this task in the past 5 years (Agogué, Kazakçi, et al., 2014; Agogué, Poirel, et al., 2014).

Participants of the group "Abstract" were provided with another additional guideline, imposing constraints on a more abstract level of these examples inside fixation, namely categories of these examples. The guideline stated that: "The evaluation of your manager will be based on the number of original ideas you will propose, knowing that your solutions must neither dampen the shock, nor slow the fall, nor protect the egg". These three abstract examples were considered the three categories of fixation of the present creative ideation task (Agogué, Le Masson, Dalmasso, Houdé & Cassotti, 2015; Agogué, Kazakçi, et al., 2014; Agogué, Poirel, et al., 2014; Cassotti, Agogué, et al., 2016; Cassotti, Camarda, et al., 2016; Ezzat et al., 2017).

DATA ANALYSIS

The creative performance of the participants of the hen's egg task was quantified by measuring the number of solutions participants were given inside and outside fixation (Agogué et al., 2015). This could be done using an existing cartography of solutions of the hen's egg task, representing the distribution of solutions across different categories. To perform this measure, two trained raters assigned each of participants' solutions to one of the ten categories of solutions. The obtained inter-rater reliability score was 92%. Only three categories among the ten were assigned inside fixation (damping the shock, slowing the fall, and protecting the egg). All solutions outside these three categories were assigned outside fixation (modifying the properties of the egg, acting before/after the fall, or using a living device, etc...). Given that creativity requires both novelty/originality and usefulness/feasibility, we applied an external rating procedure to assess feasibility. More specifically, two independent raters were instructed to evaluate each idea on a five-point rating scale ranging from 1 ("not feasible at all") to 5 ("highly feasible"). The raters displayed satisfactory intra-class correlation (ICC = 0.90).

We also computed an objective measurement of the originality of the solutions by considering the frequency of the responses provided by all participants. For this score, the originality of a solution was defined as the normalized statistical infrequency of that particular solution. A mean originality score was calculated for each participant, which could range from 0 to 1 (0 represented lower originality and 1 represented higher originality).

RESULTS

In order to examine whether the numbers of proposed solutions (ideational fluency) inside fixation (fixation) and outside fixation (expansion) varied according to the experimental conditions, we conducted a repeated-measures analysis of variance (ANOVA) with the experimental conditions (specific; control and abstract) as a between-subjects factor and the category of solution (fixation vs. expansion) as a within-subjects factor. We used the partial eta squared (η_p^2) and Cohen's d to assess the effect size.

The ANOVA revealed a main effect of the category of solution ($F(1, 72) = 7.83$, $p = .007$, $\eta_p^2 = .10$) indicating that the participants provided more solutions in the fixation path than in the expansion path. This analysis also showed a main effect of the experimental conditions ($F(2, 72) = 4.13$, $p = .02$, $\eta_p^2 = .10$). Moreover, there was a significant experimental conditions × category of solution interaction ($F(2, 72) = 48.06$, $p < .0001$, $\eta_p^2 = .57$, see Figure 1a). Critically, the experimental conditions × category of solution interaction was still significant after controlling for the feasibility scores, $F(2, 71) = 32.70$, $p < .0001$, $\eta_p^2 = .48$).

Because main effects were modulated by the two-way interactions, we focused further analysis on the latter. Planned comparisons, corrected with a Holm–Bonferroni procedure, revealed no significant difference

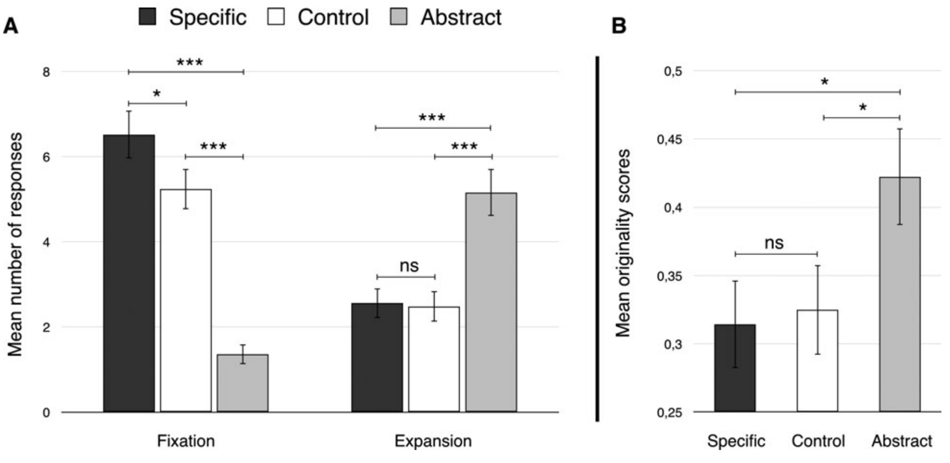

FIGURE 1. (A) Mean number of responses according to the experimental condition (Specificity/Control/Abstract) and the type of solution (Fixation/Expansion). (B) Mean originality scores according to the experimental condition (Specificity/Control/Abstract).

between the number of solutions in the expansion path in the control group (M = 2.48, SD = 1.78) and those in the group "specific" (M = 2.56, SD = 1.74, $F(1, 72) < 1$, d = .04). However, participants of the group "abstract" (M = 5.16, SD = 2.76) proposed much more solutions in the expansion path compared to the control group (M = 2.48, SD = 1.78; $F(1, 72) = 19.48$, $p_{corr} < .0001$, d = 1.15), and to the group "specific" (M = 2.56, SD = 1.74, $F(1, 72) = 18.34$, $p_{corr} < .0001$, d = 1.13).

Interestingly, the participants of the group "abstract" (M = 1.36, SD = 1.15) proposed fewer solutions in the fixation path than did those in the control group (M = 5.24, SD = 2.35; $F(1, 72) = 38.43$, $p_{corr} < .0001$, d = 2.1), as well as did the participants of the group "specific" (M = 6.52, SD = 2.8; $F(1, 72) = 67.97$, $p_{corr} < .0001$, d = 2.41). Additionally, the group "specific" (M = 6.52, SD = 2.8) proposed more solutions in the fixation path than the control group (M = 5.24, SD = 2.35; $F(1, 72) = 4.18$, $p_{corr} = .04$, d = 0.5).

To examine whether originality scores varied according to the experimental conditions, we conducted a one-way analysis of variance (ANOVA) with the experimental conditions (specific; control and abstract) as a between-subjects factor. We used the partial eta squared (η_p^2) and Cohen's d to assess the effect size. The ANOVA revealed a main effect of the experimental conditions ($F(2, 72) = 3.18$, p = .047, η_p^2 = .08, see Figure 1b). Planned comparisons, revealed no significant difference between the originality scores of the control group (M = 0.32, SD = .16) and those of the group "specific" (M = .31, SD = .18, $F(1, 72) < 1$, d = .06). However, the solutions proposed by the group "abstract" (M = .42, SD = .16) were more original than those provided by the control group (M = .32, SD = .16, $F(1, 72) = 4.26$, p = .04, d = .62) and the group "specific" (M = .31, SD = .18, $F(1, 72) = 5.24$, p = .025, d = .65).

DISCUSSION

In the present study, we demonstrated that according to the level of the specificity and abstraction of common examples presented prior to a creative idea generation task, we could obtain opposite effects on fixation mitigation. We showed that (a) instructing participants to avoid using common examples when formulated with a high level of specificity increases fixation, and therefore constrains participants' capacity to generate creative ideas; whereas (b) instructing participants to avoid such examples while using a more abstract level for stating these common examples—such as a categorization of these examples—mitigates fixation, and consequently increases the number of creative ideas generated—and in quite a significant way.

More precisely, statistical results show that constraints on common examples, formulated with high level of specificity, lightly increase the number of solutions inside the fixation path, but however have no effect on the number of solutions outside the fixation path. However, statistical analysis shows that constraints on common examples, formulated with high level of abstraction—such as a categorization of these examples—approximately reduce the number of solutions inside the fixation path by more than one third, and surprisingly double the number of solutions outside the fixation path. Thus, the magnitude of the stimulation effect produced by explicit warning of not using certain categories is quite surprising and requires some discussion.

Theoretically, these findings might suggest that when constraints on examples are formulated with high level of abstraction, individuals are forced to reason outside fixation, and therefore succeed to generate novel alternatives to the common and typical categories of solutions provided to them (outside the fixation path). Whereas, when constraints on examples are formulated with high level of specificity, individuals are more affected by the specific examples provided to them, and follow the path of least resistance, which consist of generating alternatives to the common and typical solutions (inside the fixation path).

These findings first of all confirm the studies regarding the negative role of examples for creativity (Agogué, Kazakçi, et al., 2014; Jansson & Smith, 1991; Smith et al., 1993), since the results of the group "specific" showed that the introduction of a common example with high level of specificity could highly increase fixation effect, and therefore constrains the capacity of individuals to generate creative ideas.

Secondly, our findings add to the literature on new practical procedures to overcome fixation effects in creative ideation contexts (Agogué, Kazakçi, et al., 2014; Linsey et al., 2010; Moreno, Yang, Hernández, Linsey & Wood, 2015; Zahner, Nickerson, Tversky, Corter & Ma, 2010), through the appropriate use of constraints and warnings. We demonstrate that two types of constraints could have opposite effects on fixation modulation, according to their level of specificity and abstraction. The more constraints on inappropriate examples are abstract, the more fixation effect is mitigated. Similarly, the more the constraints on inappropriate examples are specific, the more fixation effect is facilitated.

Thirdly, our findings raised more questions than what they contribute to, especially regarding the crucial role of categorization in creative ideation contexts. First of all, the present study confirms previous studies (Baughman & Mumford, 1995; Nagai & Taura, 2009; Ward et al., 2004) regarding the important role of abstraction for fixation mitigation. Furthermore, since we explicitly measure the number of solutions inside/outside the fixation path in the present experiments, using the statistical measurement of the variable "expansivity" (Agogué et al., 2015), our findings present further evidence regarding the key role that could be played by categorization for fixation modulation and creativity.

Finally, from a purely managerial perspective, our findings are consistent with the view of the literature on expertise and categorization (Chi, Feltovich & Glaser, 1981), arguing that experts have the skills to both recognize and restructure problems (Akin, 1990), in a way in which it allow them seeing the problem from a broader and more abstract view than novices. Additionally, it gives new sights for understanding how leaders could brief their teams through initial instructions in creativity situations, in a way they could help their teams to avoid falling in the cognitive trap of fixation, and stimulate their creative performance (Carson & Carson, 1993; Chaffois, Gillier, Belkhouja & Roth, 2015; Ezzat et al., 2017; Runco, Illies & Eisenman, 2005). We show that it is not sufficient and enough for leaders to simply impose constraints on unwanted ideas and solutions in creative projects for their teams, but leaders must have the ability to formulate these constraints in appropriate levels of abstraction, in a way that ensures fixation is majorly set aside, in order to open the way for creativity to flourish.

One possible limitation of our study was that we considered common or less novel ideas and solutions generated by participants, consisting of "damping the shock", "protecting the egg", or "slowing the fall", as fixation categories. In fact, we did not measure or pretest in the present experiment whether the participants have used that techniques for similar purposes (avoid breaking objects) before. In line with this limitation, further experiments could consist of controlling this specific fixation issue using previous techniques tested on creative idea generation task (Benedek et al., 2014; Silvia, Nusbaum & Beaty, 2015) to assess whether individuals' responses were based on "old" (responses retrieved from memory) or "new" (responses generated on the spot).

CONCLUSION

The present study demonstrates that common examples—if formulated in a high level of abstraction—can play a crucial role to help individuals overcome fixation effects occurring in creative idea generation situations. Our results clearly suggest that the way the common examples are formulated prior to a creativity task—either with specificity or abstraction—could have opposite effects on fixation. As a result, the present study provides new insights to the literature on the positive and negative role of examples in creative ideation.

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Axe 4 : Innovation soutenable, régimes et écosystèmes de conception

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Design Theory for Generating Alternatives in Public Decision Making Processes

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Abstract
Literature about public decision making experiences, including stakeholders' engagement, offers best practices but also reports of unsuccessful case studies. Meaningful participation activities require direct integration of stakeholders into all the phases of the public decision process to unleash innovation. Often, policy making incorporates participation late in the process, after the problem definition has occurred, alternatives have been defined, without considering stakeholders' knowledge and problem understanding. The early stage of policy alternatives design is essential to the development of policy. Our research presents an extensive literature review with respect to policy design and design theory in order to show that the formal process of generation of alternatives has been little investigated. There is a demand for methodologies aiming at supporting policy makers and relevant stakeholders during policy design. In this regard, this paper introduces (and explores) the operational role of design theory in the policy making process for the generation of policy alternatives. Design thinking, as a way to inform a collective problem definition leading to innovation, highlights the value of early stakeholders' engagement. The aim of this paper is to understand, from an operational point of view, what "design" means in a policy making context, developing an innovative approach for assisting the formalization of policy design. The paper uses the results of a pilot case study to illustrate the application of the Concepts–Knowledge (C-K) theory framework to support the innovative design of policy alternatives for the groundwater protection policy of the Apulia Region (southern Italy).

Keywords Decision analysis · Policy design · Participatory process · Policy analytics · Policy co-production · Design theory

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1 Introduction

Governments and public bodies are beginning to involve stakeholders and the general public to a far greater extent than before in the public decision process (Bayley and French 2008). Public participation is widely documented as being a valuable component of policy making (e.g. Beierle and Cayford 2002), bringing the problem of facilitating stakeholders' contributions and building collective commitment (Eden and Ackermann 2013).

Policy making that includes stakeholders offers best practices but also examples of unsuccessful case studies (e.g. Creighton 2005; Howlett 2011a; UNDP 2012; Webler and Renn 1995). Actors with different stakes, points of view, rationales, and values are brought together to participate in public decision making processes (Fischer et al. 2007). Initially, policy making has been considered to be a linear path from problem definition to options evaluation (Mintrom and Luetjens 2016). Participation was traditionally reserved for political authorities and external experts (Celino and Concilio 2011). Indeed, experts' contributions received more attention than local stakeholders' knowledge (e.g. Eden and Ackermann 2004; Ostrom 1990). However, thanks to the increasing awareness of the complexities facing the public sector, this view has been challenged (see recently De Marchi et al. 2016; Tsoukiàs et al. 2013). Instead of a rational selection among given policy alternatives, public decision making becomes the result of a collaborative process (Nogueira et al. 2017; Sabatier 2007). As such, the development of a shared understanding among all involved actors is a prerequisite for the successful implementation of a collaborative process (Oppl 2017).

Many academic studies have investigated participation, suggesting that all modes of public participation can potentially benefit society (e.g. Beierle 2002; Daniell et al. 2010; French et al. 2007; Gregory et al. 2005; Lavin 2010). Furthermore, stakeholders participation has been investigated in the field of decision analysis where stakeholders' problem frames, knowledge and preferences are considered pivotal elements of the policy making process. For interested readers Ferretti et al. (2019), soft systems methodologies and problem structuring methods (Checkland 2000; Pollock et al. 1994; Rosenhead 2006), group modelling (Vennix 1996), system dynamics (Sterman 2000), stakeholder strategic management (Ackermann and Eden 2011; Freeman 2010), meta-planning knowledge management (Wilensky 1981), strategic choice approach (Friend and Hickling 1987), collaborative decision making approach (Zarate 2013).

Although the specialized literature recognises the use of public participation necessary, it expresses doubts on the used methodologies (e.g. French and Bayley 2011; Rowe et al. 2005). Ostrom (2010) highlights the deficiency of adequate methodologies for supporting public decision making processes with multiple stakeholders. Specifically, most approaches about participation are being used to draw stakeholders into the process of deciding between different options, but not on their generation (Ferretti et al. 2019). Indeed, the mainstream decision analysis literature focuses on how to "choose" an alternative without considering how these can be established (Colorni and Tsoukiàs 2018).

Meaningful participation requires stakeholders engagement into all the phases of the process (Marttunen et al. 2013), which is not necessarily the case for most methods aimed at supporting participation and public policy making. Firstly, policy making often incorporates stakeholders late in the process, after the problem definition has occurred and alternatives have been already defined, raising the risk of the consultation being construed as a formality, limiting the ability of stakeholders to seriously inform the process (Mintrom and Luetjens 2016). Secondly, most collaborative decision making procedures are perceived to be unproductive in terms of efficiently utilizing the participants' time and effectively achieving the policy objectives (Adla et al. 2011). Lastly, policy design has long been seen as a component of policy development without any operational characteristic (Howlett 2011a; Lynn and Gould 1980; Schneider and Ingram 1997). For instance, the Strategic Choice Approach, as a method facilitating collaborative processes about complex decision problems (Friend et al. 1974), improves the understanding of inter-organisational decision processes in various public policy domains and has been successfully used in supporting public policy making (e.g. Friend and Hickling 1987; Norese et al. 2015). However, it does not explicitly support the design of policy alternatives, at least not using a formal theory and a replicable procedure. Thus, the efforts for structuring problems and working towards decisions are not combined with an in-depth designing.

Stakeholders involvement in policy making increases the need for effective policy design processes (Fischer 2000). However, there seems to be a relatively small literature on how to formally design policy alternatives (Howlett 2014). Experience suggests that well-structured and formalized methods for policy design are needed to integrate knowledge from different sources, allowing transparency of the process (Renn 2006). Moore (1995) talks about the structured inclusion of different stakeholders' knowledge, in order to unleash creativity and conceive new solutions. This should represent the starting point of an effective and innovative design process (Tavella and Franco 2015). Within this context, there is a demand for methodologies aiming to support the policy makers and relevant stakeholders during the design of alternatives within the policy making process (Ferretti et al. 2019).

In this paper, we are interested in introducing (and exploring) the operational role of design theory. Design theory highlights the value of early stakeholders engagement (e.g. Buchanan 1992; Dorst and Cross 2001; Liedtka et al. 2013; Rowe 1998), challenging some current mainstream approaches of policy making (Mintrom and Luetjens 2016). Specialized literature in design theory already exists (e.g. Agogué and Kazakçi 2014), offering a range of methodologies for products development (Brown 2008). The research reported in this paper uses the derived knowledge, methods and expertise to understand what "design" means in a policy making context. It aims to contribute by creating an innovative approach for the formalization of the policy design process. It claims that design theory can improve the policy design process and that Concepts-Knowledge (C-K) theory (Hatchuel and Weil 2002) can be a suitable framework for the innovative design of policy alternatives.

The paper is structured as follows. After the present introduction, Sect. 2 depicts the mainstream approaches to policy design. Section 3 illustrates the design theory framework. Section 4 describes the proposed methodology while Sects. 5 and 6 discuss the case study, the obtained results and the lessons learned. Concluding remarks are reported in Sect. 7.

2 Policy Design

Public policies are abstract objects introducing a portfolio of interrelated actions, reflecting the policy makers' efforts to address public and societal problems (De Marchi et al. 2016). This set of actions aims to achieve a set of interconnected policy goals within a period of time (Elmore 1987; Hand 2012), through the influence on individual and collective decisions (Bemelmans-Videc and Vedung 1998).

Policy makers create policy alternatives (Howlett 2014). Thus, policy design is a critical step that enables the pursuit of innovation (Lasswell 1956) and the formulation of effective policy alternatives (Howlett et al. 2015). "The invention of policy proposals" (Lasswell 1971) is essential to the development of policies inasmuch an integral part of the public decision making process (Wildavsky 1979). A worthy policy design process has a preponderant impact on the quality of the policy alternatives being considered.

However, no significant research has examined the formal design processes for the generation of policy alternatives thus far (see Ferretti et al. 2019). Bobrow (2006) underlines that policy design is surprisingly understudied in the policy analysis literature. The roots of policy design studies can be found in the policy science literature since the 1950s, however it has received significant attention only in the past three decades (e.g. May 1981, 2003) (see Fig. 1).

In his early works on public policy making, Lasswell (1954) stated that the understanding of the policy instruments available is an important feature of both policy formulation and implementation. In the 1970s, policy design processes focused on the evaluation of the economic impact of policy instruments (e.g. taxes and subsidies), in order to support policy makers in considerations of policy effectiveness (Mayntz 1979; Sterner 2003).

Policy design research was developed during the 1980s and 1990s, involving interdisciplinary literature. The policy design literature shifted towards understanding design both as process and outcome. Several researchers and practitioners wrote about problem formulation, policy instrument choice and policy design outcomes (e.g. Howlett 2014; May 1991; Weimer 1992). In the 1980s, the policy research was interested in the links between implementation failures and policy success (Mayntz 1981; O'Toole 2000). In the early 1990s the focus was the ex-post evaluation of pol-

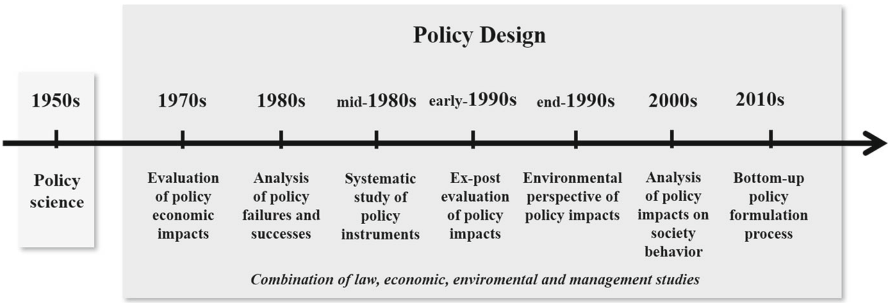


Fig. 1 Timeline showing the evolution of policy design literature

icy outcomes impacts (Bobrow and Dryzek 1987). Furthermore, an interdisciplinary approach combined economic and law studies in order to focus on policy outputs and governmental processes. On the one side, law studies analyzed how regulations mediated the delivery of goods and services, and how formal processes of rule-making led to policy (Keyes 1996). On the other side, management studies investigated the links between administrative systems and implementation modes (Lowi 1985; Peters and Pierre 1998). Specifically, both Bardach (1977) and Salamon (1981) argued that the early policy studies analyzed policy in terms of "problems" rather than in terms of "instruments of government action" and "techniques of social intervention".

A specific policy design literature appeared in the mid-1980s through a systematic study of policy instruments (Howlett 2014). Policy analysts' attention shifted from practice to theory, classifying policy instruments in order to identify the reasons of their use (Bressers and Klok 1988; Hood 1986) and to improve both policy design and outcomes (Linder and Peters 1984; Woodside 1986). In the late 1990s, policy design literature focused on instrument selection. It aimed to systematically assess the development of optimal policies by using mixed strategies, moving away from the single instrument studies of earlier works (Gunningham et al. 1998; Howlett 2004).

This period was marked by the dispersion of policy design scholars in specific fields such as economics, and environmental studies (Del Rıo et al. 2010; Howlett and Lejano 2013).

Recently, attention shifted from centrality of authority to the collaborative governance, involving non-governmental actors, among others (Howlett 2011b). Policies are seen as the outcome of a decentralized process, involving the actions of several public and private stakeholders. As a result, the implemented policy design practices became increasingly participatory and consultative in nature (e.g. Alshuwaikhat and Nkwenti 2002). They replaced previous top-down processes dominated by government analysts with bottom-up ones. The demise of policy design research could be associated with the change in demand for more collaborative governance (e.g. Hysing 2009; Levi-Faur 2012).

Under a decision sciences perspective, Simon (1954) suggested attention to procedural rationality in wicked situations such as public policy making, i.e. when substantive rationality is impossible or inappropriate. He stressed the importance of design processes to support decision making based on human deliberation. Procedural rational approaches are based on the discovery of new alternatives, i.e. in such situations, it is not a question of comparing options that are known for developing acceptable solutions (Pidd 2004). The identification of a new set of alternatives intended to be a collaborative process for the resolution of conflicts between antagonistic or bounded stakeholders.

Lastly, policy design has been investigated as depending on the design of products and services (Alford 2009). Considering that design thinking is essential in product development (Brown 2009; Martin 2009), traditional public policy making contemplates policy development from a design theory prospective (e.g. Howlett 2011a; Lynn and Gould 1980). Whilst policy making constitutes a design activity, it is yet to be discussed in design terms (Mintrom and Luetjens 2016).

The lack of methodologies for the generation of policy alternatives can be managed by introducing design theory based approaches. This paper aims to contribute to the establishment of a methodology by formalizing the process of innovative design of policy alternatives. For this reason, we consider important to analyse the design theory literature in the next section.

3 From Rule-Based Design to Innovative Design: The Genesis of the C–K Theory

Design is defined as a process of changing an existing situation to a desired one (Simon 1969), through the conception and description of an idea (Alexander 1982). The present section aims to present the key elements of the design theory in order to clarify its possible use for the policy design process.

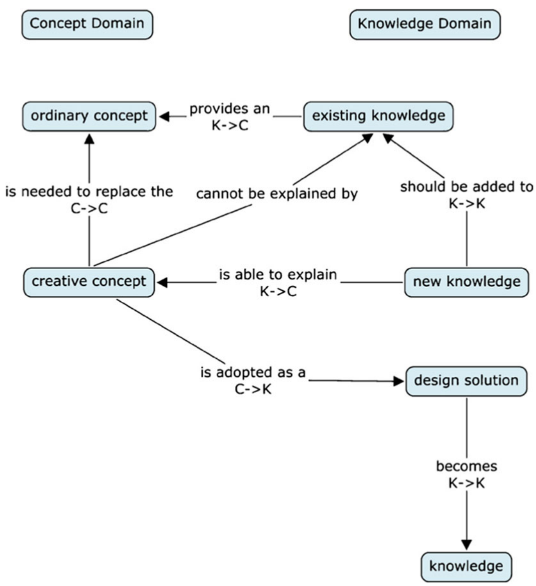
The early design theory is characterized by the desire to understand design as a systematic process, based on objectivity and rationality: design tasks are broken down into simplified sub-tasks (Alexander 1964) through abstract mathematical notation (Archer 1965, 1970) within repeatable procedures (Forester 1999). The main focus of early design theory is the attempt to incorporate scientific knowledge and engineering techniques into a rational design process (Bayazit 2004). It generates adapted solutions to well-formulated requirements within a systematic reasoning (Elmquist and Segrestin 2009). For instance, the axiomatic design approach (Suh 1990) characterizes the quality of the design process through a two-dimensional matrix analysing types of parameters describing a given object (Agogué and Kazakçi 2014). The rule-based design methodologies are based on the "dominant design" of objects, helping firms to face the growing need for a mass production around well-identified objects (Elmquist and Segrestin 2009). According to Utterback and Abernathy (1975), the dominant design, identifies key features and attributes that become standard over the evolution of the industrial dynamics (see the key contribution of Pahl and Beitz 1984). Consequentially, conceptual breakthroughs are rare (Hatchuel et al. 2015). The rule-based design is unable to describe objects outside their dominant patterns, moving around its known and stable characteristics and design activities are structured around known performance parameters, establishing of optimized product lines process (Agogué and Kazakçi 2014).

On the other side, the modern generation of design theory explores "disruptive innovation challenges", modifying the characteristics of objects (Hatchuel et al. 2008). In order to provide breakthrough innovations, the properties of the object are challenged. The attributes of products are questioned, and new expertise may need to be developed (Elmquist and Segrestin 2009). With a purpose to meet such challenges, Hatchuel and Weil (1999) aimed to analyse the mechanisms of innovative design through the development of the Concepts–Knowledge (C-K) theory where the design is defined as a generative process which something unknown can intentionally emerge from what is known. From the beginning (Hatchuel and Weil 2002), the features of C–K theory were recognized as being unique for describing creative reasoning in the design process of generating alternatives (Ullah et al. 2012). Over the last few years, C–K theory has gained a growing academic and industrial interest (Agogué and Kazakçi 2014). C–K is a theory of reasoning for innovative design situations, overcoming the limits of traditional design theory (Hatchuel et al. 2015) and creativity methods (Kazakçi and Tsoukiàs 2005). It provides researchers and practitioners with a framework to describe and analyse innovative design processes for the generation of alternatives. Indeed, C–K theory goes beyond two traditional design axioms: (i) the design reasoning is arranged on a stabilized set of functions (i.e. rule-based design); (ii) creativity in design is interpreted as an uncontrollable process of idea generation (Hatchuel et al. 2004).

C–K theory is based on the distinction between two expandable spaces: a space of Concepts (C-space), and a space of Knowledge (K-space). The process of design is thus defined as the co-evolution of C- and K-spaces through four types of independent operators (C - C, C - K, K - C, K - K). According to Hatchuel and Weil (2003), the K-space is a space of propositions that have a logical status (i.e. “true” or “false”) for a designer. Whereas, the C-space is a set of propositions describing an object, that has no logical status in the current K-space: when a concept is formulated, it is an “unknown” entity, and it is impossible to prove that it is a proposition of the K-space. A concept expresses a group of properties qualifying a given entity, such as “C: there exist an object x with the properties p_1, p_2, … , p_n” (Agogué et al. 2014). Therefore, within the C–K theory, the design activity is defined as the process by which a concept generates other concepts or is transformed into knowledge, i.e. the co-evolution of the C- and K-spaces (Le Masson et al. 2014). Figure 2 illustrates an example of how the operators could be structured.

Within a given design process every C-space has a strong dependency on the related K-space. Every element and possible expansion in the C-space relays on the structure and contents of the Knowledge base (Hatchuel et al. 2004). Once the designer imagines something new, he/she creates new concepts (expanding the C-space) and he/she activates simultaneously new knowledge (expanding the K-space). These expansions

Fig. 2 A schematic illustration of C–K theory operators (Ullah et al. 2012)



are complementary: a new knowledge provokes the identification of new concepts and elaboration of new concepts results in the search process to acquire new knowledge. Thus, C–K theory proposes a formal framework for structuring the complementary expansions, supporting the generation of new concepts.

Building a C–K model (Fig. 3) with different design paths and various levels of mastery of the K-space, leads to the definition of the C-space with the existing dominant design of the object and possible pathways expansion (i.e. identification of new alternatives) (Agogué et al. 2014).Within a C–K model, the C-space, is structured as a tree including three different types of C-paths: (i) describing the attributes of the existing dominant design related to validated knowledge (items in light grey in Fig. 3), (ii) characterizing concepts that are reachable and attainable using existing knowledge or its recombination (items in mid grey in Fig. 3) and (iii) outlining new alternatives, through the C-space expansion combined with the further exploration of the K-space (dark grey in Fig. 3). This evolving structure helps to identify fixation effects and lack of information that limit the ability to generate novel ideas.

C–K theory offers a formal framework, providing a definition of the design process independent of any domain, where creative thinking, learning process, knowledge structuring, knowledge sharing, and innovation principles are not external phenomena but are the central core of the theory itself. Therefore, C–K theory helps to analyse the limits of traditional methods of collective creative design (Hatchuel et al. 2015). Methods of harnessing group creativity, such as more or less sophisticated brainstorming, tend to lead to a consensus with very few breakthroughs. On the other hand, potential well-structured creativity task forces are not able to follow the creative breakthrough due to the limited size of the Knowledge base or the lack expert inputs. C–K theory is used to overcome these constraints while creating a formal framework for collectively innovative design processes (Hatchuel and Weil 2009).

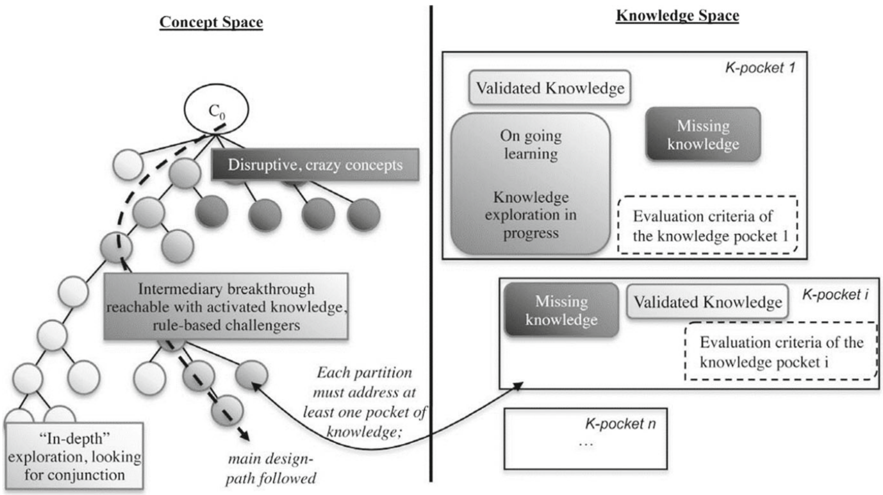


Fig. 3 The C–K model (Agogué et al. 2014)

3.1 The KCP Tool for Innovative Collective Design Activities

According to the C–K theory theoretical framework, the design reasoning is interpreted as the co-evolution of the C- and K-spaces. This co-evolution allows to formally describe the learning process (K-space expansion) and to decode the way in which new knowledge supports the generation of new concepts (C-space expansion).

Operationalizing the C–K theory, the KCP methodology (i.e. K for knowledge, C for concepts and P for proposals) was developed to manage collaborative design process, where many participants are involved (i.e. experts, users, researchers, engineers, designers, customers, …) (Hooge et al. 2016). The KCP, described in detail by Hatchuel and Weil (2009) and Agogué et al. (2014), is composed by three phases briefly outlined below:

3.1.1 K Phase

K-sessions aim to collectively build and share the available knowledge about a given object under design. They consist of several days of seminars in which experts make presentations. The knowledge-exchange activities can be both internal to the design team (i.e. sharing internal knowledge usually compartmentalized in different departments and unshared) or external involving experts. This phase does not contain any creative activity and allows to open up new perspectives in a field of knowledge with an exploration scope. At the end of this phase, the team is able to (re)structure the K-space, identifying possible polysemy and ambiguity, isolating conventional forms of design to highlight paths of possible breakthrough. The K-phase can reveal some weaknesses in the initial individual K-space, in order to prepare for future C-space expansion.

3.1.2 C Phase

The C-phase consists of a series of generative sessions during which the design team is involved in a "conceptual building effort". It aims to activate and encourage unexpected concepts-exploration. The output of the C-phase are detailed proposals of innovative concepts. C–K theory differs from creativity techniques such as brainstorming in the way that disruptive paths are explored through pre-defined concepts that guide the creativity session (i.e. contrary to brainstorming, relying on free divergence, the C-phase manages a divergence phase).

3.1.3 P Phase

The last phase consists in synthesizing the outcomes of both the K- and the C-phases into a structured innovative design strategy. It focuses on the identification of different design paths. The P-phase aims to engage actors at all levels, by making them informed and aware of learning issues. The P-phase helps the decision makers, to assimilate the structure of the innovation field, to keep the variety of alternatives and avoid focusing on one apparently dominating solution.

In conclusion, the KCP methodology has been successfully used in a variety of contexts ranging from large companies in the transport sector to agricultural cooperatives or firms from the energy industry (Agogué et al. 2014). It is lacking however, any application with respect to the more complex issue of public policies. To this end, the paper proposes a new participatory tool for the innovative design of policy alternatives, based on the KCP and within the C–K theoretical framework. The paper introduces and explores the possible role of design theory in the policy making process. There are a practical and a theoretical reason: how can one practically employ the KCP methodology for policy design? Does C–K theory need to evolve and adapt with respect to policy design? A pilot case study aiming to extend the KCP methodology in the area of policy design is presented in the following sections.

4 Policy-KCP: A Systematic Generative Mechanism for the Design of Policy Alternatives

The Policy-KCP (P-KCP) is a participatory tool for the innovative generation of policy alternatives. It is a C–K theory drive tool, adapted to the design of abstract objects such as public policies. The P-KCP aims to formalize the innovative design of policy alternatives within a public decision making process. A formal methodology is developed allowing systematic design of public policies that can go beyond traditional policy alternatives. The PKCP supports the creation of a shared artefact (Ostanello and Tsoukiàs 1993), further motivating stakeholders engagement and commitment to a participative policy making process. The steps of the P-KCP participatory tool are described in the following.

4.1 Policy–Definition Phase (P–D Phase)

The preliminary phase aims to determine key topics and relevant expertise, underpinning the development of policy alternatives. It identifies the relevant stakeholders and supports the initial problem formulation of the policy issue under analysis. Firstly, the policy design management team defines the list of suitable participants. In order to support the stakeholders engagement process, it is important that the participants are chosen based on their ability to inform the process and to be knowledgeable about it. In participatory approaches, stakeholder analysis has been seen as a way of generating information on the relevant actors to understand their behaviour, interests, agendas, and influence on decision making processes (Brugha and Varvasovsky 2000; Reed et al. 2009). Usually, in order to minimise the selection bias and the marginalization of stakeholders (Ananda and Herath 2003) a top-down stakeholder identification practice, namely "snowballing" or "referral sampling", is implemented (e.g. Harrison and Qureshi 2000; Reed et al. 2009). At the end, the stakeholder analysis leads to an in-depth characterization of the relevant actors, their objectives (Lienert et al. 2013) and the relationships between them (Giordano et al. 2017b).

Secondly, the collected knowledge is structured in the initial problem formulation. In public decision making processes, the problems are often complex and wicked (De

Marchi et al. 2016; Rittel and Webber 1973) and stakeholder groups have different perspectives that need to be incorporated in a participatory process (Marttunen et al. 2013). Differences in problem framing and understanding are unavoidable, deeming ambiguous problem definitions (Santoro et al. 2019). On the one hand, a diversity in frames can enhance the co-production of knowledge, offering opportunities for innovative solutions. On the other hand, the presence of ambiguity can be a source of discrepancies or conflict in a group, hampering the implementation and/or reducing the effectiveness of the policy (Giordano et al. 2017a). Thus, preliminary interviews allow to define an initial problem understanding, underlining the differences between the stakeholders' points of view.

The expected outcomes are: (i) a preliminary synthesis of the state-of-the-art knowledge, (ii) a stakeholder analysis with the depiction of objectives and values, and (iii) a preliminary analysis of the different problem understandings according to the stakeholder's perceptions.

4.2 Policy–Knowledge Phase (P–K Phase)

The aim of this phase is to reach a collective problem formulation agreed upon by all the involved participants. This is accomplished by gathering missing information and building a comprehensive summary of current knowledge about the policy issue under consideration. Thus, the P–K phase provides the creation of a shared base of knowledge supporting the following generative phase, i.e. P–C phase. The management team combines the outputs from the stakeholders analysis and the initial problem formulation with scientific literature studies, available data, emerging technologies, best practices, current policies, etc. Afterwards, individual meetings with stakeholders complete the problem formulation stage. The individual meetings are organized as semi-structured interviews, where participants' opinion and knowledge concerning the specific policy problem is investigated. Interviewees are free to share their personal knowledge about the given topic. A report of each interview is validated with the interviewed.

This phase supports the building of the overall K-space combining the individual (intermediary) K-spaces, in order to reach a common understanding between each viewpoint. It allows to: (i) clarify the existing knowledge, identifying also missing studies, models, and action plans; (ii) integrate new stakeholders' views into the initial problem formulation; (iii) identify potential barriers or preconditions to work with stakeholders; (iv) analyze what competencies stakeholders need before the generative process starts in terms of motivation, knowledge, and practical expertise, in order to be able to effectively participate to the P–C phase.

The expected outcomes are: (i) a summary of the complete state-of-the-art knowledge on the case study and policy issue under analysis, (ii) an improved and detailed stakeholder analysis, (iii) the definition of the common problem formulation including the individual points of view and (iv) the identification of the dominant design concerning the traditional policy alternatives represented via a preliminary C-tree model. At the end of the P–K phase, the document summarising the complete K-space is shared with all the participants in order to prepare them for the following phase.

4.3 Policy–Concepts Generation Phase (P–C Phase)

The aim of the P–C phase is to generate policy alternatives using the C–K theoretical framework. It consists of 1-day generative workshop with a group of participants and it is divided in four steps. Firstly, the common problem formulation is shared, discussed and validated in order to build a common knowledge ground and a collective shared problem formulation for the generative workshop. Secondly, the preliminary C-tree is explained to all the participants. Afterwards, the participants are divided into heterogeneous groups, in order to collectively evaluate and discuss the elements representing the policy dominant design and to suggest the expansions of the C-tree. During this step, each group needs to agree upon the evaluation of the alternatives and C-expansion, leading to a facilitation of a "local" process of defixation. Lastly, a general discussion on the group activities is concluding the workshop, as starting point for the participatory learning process.

The C-space allows to illustrate various alternatives as concepts connected to the initial concept (C0) thanks to the tree-like structure. It represents the map of all possibilities where alternatives are broken down and represented in the form of a concepts-tree. The tree structure highlights the dominant design and improves the search among alternatives branches, thus designs. The C-tree for the innovative design of policy alternatives displays different exploration paths. Figure 3 shows an example of C-tree (Agogué et al. 2014). The left paths describe the genealogy of known objects, i.e. the hierarchy of attributes stabilized in the dominant design. The central branches outline the first C-expansions allowed by the incremental addition of knowledge or the re-organization of existing K-space. Finally, the right side of the C-tree displays the expansions leading to innovative policy alternatives, which are not explored in the K-space yet.

4.4 Policy-Project Phase (P–P Phase)

The P–P phase uses the K-space and the C-tree generated in the previous steps, to build a set of policy recommendations, including the innovative set of policies alternatives. Similarly to the KCP approach, an expert team is involved in this phase to test feasibility of the policy alternatives identified and to evaluate them. Considering the different phases of a decision-aiding process (Tsoukiàs 2007), the P–P phase supports the decision-making process by considering the whole range of possible methodologies for the evaluation of alternatives.

The developed P-KCP participatory tool to formally support the design of policy alternatives has been applied to a pilot case study concerning an environmental policy design problem described in the following section. The pilot case study focuses on the generation of policy alternatives (P–D, P–K and P–C phases) and the possible contribution of its outputs to a following evaluation phase (P–P phase).

5 The Groundwater Protection Policy Within the Agricultural Sector of the Apulia Region (Southern Italy)

The purpose of this section is to illustrate the implementation of the P-KCP participatory tool (described in Sect. 4) for the innovative generation of policy alternatives in a pilot case study. It is worth underlining that the alternatives' evaluation represents the subsequent phase of the decision aiding process (Tsoukiàs 2007). For this reason, this paper details the alternatives' design phase, i.e. how to build the C-space and the related K-space. The case study discusses the groundwater protection policy and water management within the agricultural sector of the Apulia Region (southern Italy).

5.1 Case Study Description

The area is located in the north of the Apulia Region (southern Italy) and is characterized by the combined use of surfacewater (SW) and groundwater (GW) for irrigation. The strong GW dependency of the agricultural sector and consequential overexploitation generates social and environmental problems. Specifically, the Capitanata Irrigation Consortium (IC) provides SW management, ensuring an adequate technical and administrative assistance to farmers (Giordano et al. 2015). The SW annual availability depends strictly upon weather conditions and rainfall patterns, in an area characterised by recurrent drought events. The Regional Authority needs to protect GW quality and at the same time to preserve high productivity standards for the agricultural sector. In 2009, the Regional Authority implemented the Water Protection Plan, in order to significantly restrict the GW use (according to the European Water Framework Directive, CEE 2000/60).

Based on a traditional policy design approach, this policy was defined without considering the potential impacts on the other stakeholders (i.e. farmers and IC) and it caused strong conflicts (Giordano et al. 2013). The policy resistance mechanisms mainly occurred due to the economic damages to the agricultural sector, highly dependent on the water-demanding crops and irrigation practices (Giordano et al. 2017a). On the one side, the IC has to deal with the water shortage and with the farmers' water requests. It uses an increasing pricing strategy (based on the Water Protection Plan), defining two different price thresholds for the SW: the base water supply volume (0.12 €/m^3 for 2050 m^3/ha) and the additional water supply volume considerably more expensive (0.36 €/m^3 for 2050–4000 m^3/ha). In the IC's problem understanding, this policy would force farmers to reduce the irrigated areas and/or to select less water demanding crops, without considering the GW alternative (Ferretti et al. 2019).

On the other side, each farmer maximizes her/his profits by choosing the crop plan with regard to the quantity of available water (i.e. SW and GW) and the hectares of arable land owned. The base water supply volume is not adequate to cover the water request. Within this situation, each farmer can choose between two alternatives: paying for the additional water supply volume (sold by the IC) or using the GW, a cheaper (approximately 0.19 €/m^3) and easily accessible resource. Thus, the use of GW is restricted by the Water Protection Plan but the price of the additional water volume is higher than the price of GW withdrawal. Even if the GW quality is lower than the water managed by the IC, farmers tend to prefer the use of GW. The farmers perceive the price for the additional water volume as unsustainable (Ferretti et al. 2019). Therefore, they use the base water supply volume, combined with the GW for the remaining water demand. A detailed description of the case study can be found in Giordano et al. (2017a) and Pluchinotta et al. (2018).

Given this context, the P-KCP tool aims: (i) to allow a collective and participatory discussion on the water management issue, in order to reach a shared understanding of the different problem framing; (ii) to contribute to the conflicts mitigation and to the renewed understanding of the problems by all parties; (iii) to ensure a better participation of all the stakeholders and integration of their knowledge, in order to overcome the limits of the traditional methodologies; (iv) to suggest novel alternatives for the GW protection policies and water management strategies within the agricultural sector.

From a methodological point of view this paper aims: (i) to test and validate the effectiveness of a C–K based tool for the innovative design of policy alternatives within the policy cycle; (ii) to showcase a proactive approach, supporting research and proposing a "best practice" participatory processes as an example to improve the policy design process.

5.2 The Policy-KCP Participatory Tool for the Innovative Generation of Policy Alternatives

5.2.1 P–D Phase

During the pre-workshops activities, the policy design management team outlined a first list of relevant participants, determining which stakeholder is involved in or affected by the policy issue under investigation. As stakeholders were considered all the individuals, groups, or institutions related to the policy problem with common or conflicting objectives. Further details on the identified stakeholders and their role are showed in Table 1. To make sure that all relevant stakeholders were included in the process, the selection process starts with the identification of the stakeholders mentioned in official documents, reports, and institutional protocols. Thereafter, preliminary interviews with experts and institutional actors allowed to widen the set of stakeholders to be involved (examples of questions are: which stakeholder should be involved in the policy design process and in the P-KCP workshop? Why? What is your viewpoint concerning the policy goal? What are the other stakeholders' viewpoints? etc.) The profile of each possible participant was created including objectives and perspectives of the GW management problem. Moreover, the relationships with other stakeholders were investigated in order to detect conflictual situations [using the Interaction Space model defined in Ostanello and Tsoukiàs (1993) and applied in Giordano et al. (2017a). Previous research activities on the same case study supported this preparatory phase (e.g. Portoghese et al. 2013; Giordano et al. 2015; Pluchinotta 2015). The D-phase allowed an initial definition of the problem formulation, i.e. reducing the GW dependence, ensuring a suitable water volume for the agriculture (C0).

Table 1 List of participants involved in the 1-day generative workshop

Stakeholders	Number of involved stakeholders	Role
Farmers—small scale	4	Water user
Farmers—large scale	3	Water user
Consortium of Capitanata—technical branch	3	Local water management authority
Consortium of Capitanata—political branch	3	Local water management authority
Regional authority	1	Regional political authority
River basin authority	2	Regional technical authority
Expert—IRSA-CNR	1	Water management and governance
Expert—IRSA-CNR	1	Water balance physical models
Expert—CIHEAM	1	Agricultural land/water governance
Expert—University of Bari	1	Agricultural economy
Management team	1	C–K theory expert
Management team	1	Decision science expert
Management team	1	Case study expert
Assistants	1	–
Observers	2	–

5.2.2 P–K Phase

The P–K phase supported the identification of the common knowledge on the GW protection and SW management problem, including the quali-quantitative state of GW aquifers and the analysis of the different stakeholders' problem framing. The knowledge elicitation activities were carried out by integrating scientific and technical evidences available in literature with expert and local knowledge (Fischer 2000; Schon 1983), according to participatory work principles. After the first round of interviews of the P–D phase, a second extended round of semi-structured interviews was carried out. The interviews inspected several topics such as the water management strategies, the peculiarities of the IC's SW management, the main characteristics of the agriculture sector and farmers' behaviours, the issues related to field controls, the known effects of the high irrigation practices on the GW aquifers state, etc. Due to the stakeholders' time constraints, K sessions and common knowledge sharing seminars were not possible (see Sect. 3.1). Nevertheless, the design management team interacted and collaborated with all the participants along all the phase. Scientific knowledge available in literature was combined with expert knowledge elicited the interviews and thanks to participatory processes performed previously on the same area (e.g. Pluchinotta et al. 2018; Giordano et al. 2017a). All the information collected was written and distributed to all the involved stakeholders, developing the first version of the P–K space. During this phase, participants started learning from other stakeholders' knowledge and realizing missing knowledge elements thanks to the P–K space. The knowledge sharing process supporting the alignment of the different stakeholder's perception of the policy issue (i.e. the social aspect of the K-sessions) was organized as the starting point of the C-phase (i.e. a general discussion at the beginning of the 1-day generative workshop). Lastly, in this phase, students supported the design management team, accelerating the time-demanding task of GW management best-practices identification. The students attending the 2017 master of ENSAM-Mines ParisTech, trained with the C–K principles, enriched the P–K space with information about innovative irrigation techniques and sustainable water management examples.

5.2.3 P–C Phase

Similarly to the traditional KCP methodology, the P–C phase includes the generation of different design paths within the C-tree. Further details on the stakeholders involved in the 1-day generative workshop are shown in Table 1. Using a color code, Fig. 6 shows the whole C-tree: (i) the branches describing the attributes of the existing dominant design of known policy alternatives are colored in black, (ii) the ones in blue indicate attainable policy alternatives use existing knowledge or a combination of K-space subsets (i.e. policy alternatives used in best practices of comparable case studies), and (iii) the paths in green represent breaking new ground policy alternatives, requiring the expansion of the K-space in order to enlarge the C-space.

Table 2 lists the elements of the C-tree (Fig. 4), underlining the concepts hierarchy and the preliminary stakeholders' interest in exploring certain alternatives (i.e. number of stakeholders considering relevant the alternative at the beginning of the process).

The expected output of the P–C phase is to frame possible innovative alternatives to be explored in the following P–P phases. Through the generative workshop, a collective problem understanding and formulation have been settled and the set of policy alternatives have been analysed and improved. During the 1-day generative workshop, the process of designing policy alternatives was supported and managed accordingly to the C–K principles of innovation management.

Table 2 List of policy alternatives generated in order to reduce the GW dependence, ensuring a suitable water volume for the agricultural sector (C0)

ID	Policy alternatives	Number of stakeholders interested in exploring the alternative	Status
C0 to reduce the GW dependence, ensuring a suitable water volume for the agriculture			
C1	Reduction of water resource use	–	–
C1.1	Not modifying the farmers' water requirements	–	–
C1.1.1	Surface water management	–	–
C1.1.1.1	Pricing strategy	–	Dominant design
C1.1.1.1.1	Pricing strategy for everyone	1	Dominant design
C1.1.1.1.1	Pricing strategy for over consumers	–	Dominant design
C1.1.1.2	Pricing strategy and controls	–	Dominant design
C1.1.1.2.1	Direct controls	2	Dominant design
C1.1.1.2.1.1	Direct controls using Acqua card	–	Dominant design
C1.1.1.2.1.2	Direct controls on the fields	–	Known
C1.1.1.2.2	Indirect controls	1	Dominant design
C1.1.1.2.2.1	Indirect controls from declared crop plan	–	Known
C1.1.1.2.2.2	Indirect controls using GIS	1	Known
C1.1.1.3	Improving the water distribution system	1	Dominant design
C1.1.1.3.1	Improving the water supply infrastructure	2	Dominant design
C1.1.1.3.2	Extending the water supply infrastructure	2	Dominant design
C1.1.1.4	Improving drought management system	–	Unknown
C1.1.1.4.1	Drought early warning system	7	Unknown
C1.1.2	Ground water management	–	–
C1.1.2.1	Concessions	–	Known
C1.1.2.1.1	Concessions—wells	–	Known
C1.1.2.1.2	Concessions—water volume	–	Known
C1.1.2.2	Pricing strategy	–	Known
C1.1.2.2.1	C1.1.2.2.1 Pricing strategy for everyone	–	Known
C1.1.2.2.2	Pricing strategy for over consumers	–	Known
C1.1.2.3	Pricing strategy and controls	–	Known
C1.1.2.3.1	Direct controls	–	Known
C1.1.2.2.1.1	Direct controls using flow meters	–	Known
C1.1.2.2.1.2	Direct controls on the GW aquifers	2	Known
C1.1.2.3.2	Indirect controls	4	Known
C1.1.1.3.2.1	Indirect controls from energetic consumption	–	Known
C1.1.1.3.2.2	Indirect controls from declared crop plan	1	Known
C1.1.1.2.2.3	Indirect controls using GIS	4	Known
C1.1.2.4	Water market between users	2	Unknown
C1.1.2.5	Shared management of GW aquifer	10	Unknown

Table 2 continued

ID	Policy alternatives	Number of stakeholders interested in exploring the alternative	Status
C1	Reduction of water resource use	–	–
C1.2	Modifying the farmers' water requirements	–	–
C1.2.1	Efficient irrigation techniques	3	–
C1.2.1.1	Rainbird irrigation	–	Known
C1.2.1.2	Drip irrigation	–	Known
C1.2.1.3	Sub irrigation	2	Known
C1.2.1.4	Sub irrigation with geotextile	–	Unknown
C1.2.1.5	Sub irrigation with condensation	–	Unknown
C1.2.1.6	Aqua4D	4	Unknown
C1.2.2	Modifying the Farmers' crop plan (CP)	3	Dominant design
C1.2.2.1	Modifying the CP with economic subsides	6	Dominant design
C1.2.2.2	Modifying the CP without economic subsides	1	Unknown
C1.2.2.2	Using OGM	–	Unknown
C2	Water resource production	–	–
C2.1	Water treatments 2	2	–
C2.1.1	Wastewater recycling	8	Known
C2.1.2	Desalinization (general suggestion)	4	Known
C2.1.2.1	Thermic desalinization	–	Known
C2.1.2.2	Reverse osmosis desalinization	–	Known
C2.1.2.3	Electrodialysis desalinization	–	Known
C2.1.3	Subsurface barriers	1	Unknown
C2.2	Water collection	2	–
C2.2.1	Rainwater collection	4	Known
C2.2.2	Water collection from the air humidity	6	Unknown
C2.3	Water resource transport	–	–
C2.3.2	From other planets	1	Unknown
C2.4	Artificial recharge of GW	9	–
C2.4.1	Using infiltration wells	3	Unknown
C2.4.2	Using infiltration trenches	1	Unknown
C2.4.3	Using infiltration fields	1	Unknown

 4.1

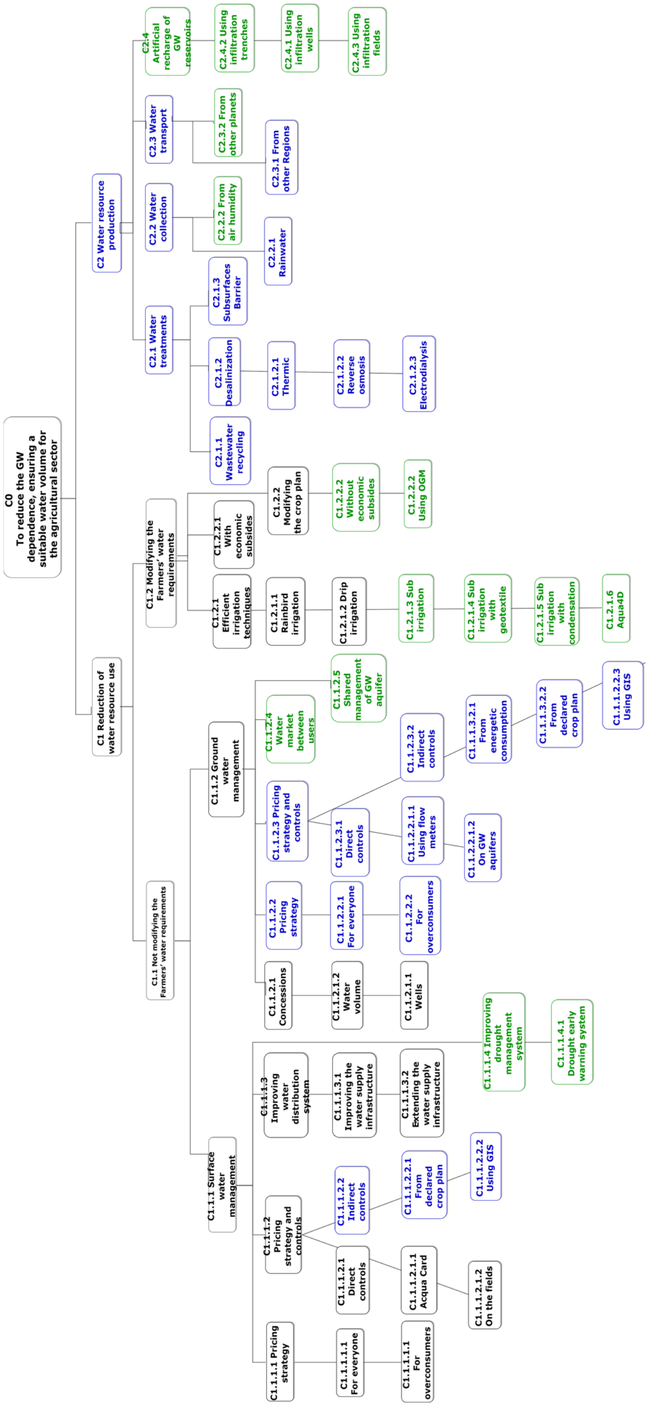


Fig. 4 The C-space showing all the policy alternatives generated

Following the P-KCP description, the 1-day generative workshop consisted of four main steps divided as follows:

1. The group discussed about the collective problem formulation starting form the different stakeholders' problem perspectives collected during the previous phase. This step focused on the definition of the GW overexploitation policy issue according to the different participants' backgrounds (Fig. 5).
2. A C–K theory expert briefly explained the C–K theoretical framework and made a general illustration of the preliminary C-tree (1 h 30 min). A detailed description of each policy alternative identified at the end of the P–K phase (i.e. dominant design) was carried out. The description of the C-tree branches was supported by the related K-space. At the end of this phase, each participant had to express preferences over the five most interesting/suitable policy alternatives for the given policy issue.
3. Small heterogeneous groups were formed to evaluate the dominant design of policy alternative and to propose innovative policy alternatives through the expansion of the C-tree. Each group had to choose at least 5 policy alternatives/elements of the C-tree and to analyse the selected items in the following ways: carrying out a collective evaluation of the items providing specific and practical observations and criticisms, defining the interest of each chosen item using scale from 1 to 5 (not useful at all to very useful for the case study), providing suggestions and group recommendations for improving the analysed items, and prompting new policy alternatives or innovative combinations of them. Table 2 lists the elements of the C-tree selected from the groups for the second part of the generative workshop.
4. A general discussion concerning the results of the small group activities and the C-tree expansion suggestions. The general discussion leads to a portfolio of preferred policy alternatives shared with all the stakeholders and to the introduction of few innovative policy alternatives.

Fig. 5 The P-KCP 1-day generative workshop hosted by the Consortium of Capitanata

Fig. 6 Group activities during the P-KCP 1-day generative workshop

5.3 The Outputs of the C-Phase Generative Workshop

During the generative workshop (Fig. 6), the groups decided to work on specific policy alternatives. All three stakeholder groups considered “Water resource production—Artificial recharge of GW reservoirs” (C2.4) and “Shared management of GW aquifers” (C1.1.2.5) to be valuable alternatives. The “Drought early warning system” (C1.1.1.1.4.1) and “Water resource production—Wastewater recycling” (C2.1.1) alternatives were discussed at length.

Perhaps the most interesting observation was the groups shifting focus from the alternatives generated via dominant design at the beginning of the workshop to the alternatives in the more innovative C-tree branches towards the last part of the workshop. The explored policy alternatives are shown in Table 3.

The workshop ended with the generation of a new set of policy alternatives: (i) delocalization of the tomato production as new option for modifying the crop plan with economic subsidies (C-tree branch C.1.2.2), (ii) sales at the end of irrigation season for the SW managed by the IC, i.e. a lower price for additional water volume in case of abundance (C-tree branch C1.1.1.1), (iii) construction of new dams and related infrastructures at different scales.

Furthermore, during the discussion, participants highlighted the need to combine policy alternatives in order to build a portfolio of actions. Specifically:

- The alternative “Water resource production—Artificial recharge of GW reservoirs” (C2.4) was proposed for increasing the water availability, considering GW aquifers as reservoirs for properly treated water. This alternative defined a new role/attribute for the GW reservoirs. The participants underlined the need to analyse the interdependencies between the alternative C2.4 and economic and management issues (e.g. the high costs of investment, the need for a detailed analysis of the aquifers state, the farmers’ will to accept). During the discussion G1 suggested that the strength of this alternative was related to the abundance of winter water flow that could be collected and reintroduced by helping the aquifer hydrologic balance in dry and summer seasons (i.e. requiring newly built storage space). Participants were inspired by the alternatives explored in the related C-tree branch and suggested implementing a decision support system to evaluate the economic and technical feasibility of the proposed sub-alternatives (C2.4.1, C2.4.2, C2.4.3) through detailed hydrological studies and analysis of current regulations.
- The alternative “Shared management of GW aquifers” (C1.1.2.5) has been recognised a promising long term policy strategy, enhancing the innovative management of GW through shared and informed decision processes. The starting point has been a specific element of the K-space brought by one stakeholder on common pool resources management, according to Ostrom (1990)’s works introduced the awareness of the attributes defining the GW resource (i.e. the K-space expansion). Thus, GW is a shared resource characterized by a highly distributed structure with several collection points (i.e. wells) in private properties. In this regard, farmers tend to deny the legitimacy of a centralized entity for its management. Furthermore, stakeholders’ knowledge clarified that the centralised “command and control” approach fails in verifying the actual number of wells and GW volume consumptions due to

Table 3 Summary of the groups' activities

ID	Policy alternatives	Groups
C1.1.2.5	Shared management of GW aquifers	G1, G2, G3
C2.4	Artificial recharge of GW reservoirs	G1, G2, G3
C1.1.1.1.4.1	Drought early warning system	G1, G2
C2.1.1	Wastewater recycling	G1, G2
C2.3.1	Water transport from other regions	G1
C1.1.2.3.2	Indirect controls of GW use	G2
C1.2.2	Modifying the crop plan	G2
C1.1.1.2.2	Indirect controls of SW use	G3
C1.1.2.3.1.4	GW aquifers monitoring G3	G3
C2.2.1	Rainwater collection	G3

high management costs. In this context, a shared GW governance could empower the farmer community through reward regulations for virtuous GW use. Shared GW governance is supported by non-centralized self-organizing management structures (i.e. groups of farmers managing shared sub-aquifers). Following the discovered GW attributes, the discussion leads to considering a distributed management system, in order to overcome the shortfalls of a centralized management for GW. At the end of the discussion, the principles of shared governance were revised by a few stakeholders and a new alternative was proposed: the IC as an integrated water resource management authority (i.e. SW and GW) through a specific GW withdrawals legislation, legitimated by a bottom-up participative decisional process in order to preserve the equal water distribution principle. For the shared management policy alternative, participants identified the necessity of: (i) a detailed database on the quali-quantitative state of the aquifers from a physical point of view; (ii) farmers' crop plan patterns from a management point of view in order to organize farms in sub-structures; (iii) a learning process via pilot a case study from the social point of view.

- The alternative "Drought early warning system (DEWS)" (C1.1.1.1.4.1) was discussed with a twofold perspective. On the one hand, all the participants recognised that a DEWS does not have a direct effect on GW availability, underlining (i.e. via a specific element of the K-space related to innovation) the differences between superficial drought and GW shortage, the latter becoming visible with a significant delay. On the other hand, some participants observed that a DEWS managed outside the IC structure, could erase the farmers' dependency on the IC information system, encouraging irrigated crop practices in case of water abundance with a major negative impact of the GW aquifers. However, the experts of the G1 highlighted that analysis based on historical data could be beneficial for supporting the annual farmer's crop planning phase through timely information on water availability.
- The "Water resource production—Wastewater recycling" (C2.1.1) was considered a pragmatical alternative despite several technical reports showing that it does not significantly increase the quantity of available water. New elements were added to

the K-space during the discussion (i.e. the IC is developing a project for introducing recycled wastewater in its distribution system). The discussion focused on the role of the IC as a management authority for an integrated water distribution system. The participants identified the following actions to be considered in a portfolio of policy alternatives: (i) to explore innovative water treatment technologies in order to expand the related C-tree branch; (ii) to develop a reliable treatment process in order to recognize the different responsibilities in the production and distribution phases; (iii) to face problems related to the recycled water quality, avoiding a decrease in crops conditions; (iv) to fairly divide the energetic consumption of the treatment plant (i.e. paid by the Farmers or by the whole community); (v) to develop strategies and infrastructures (i.e. water storage systems) in order to secure the water distribution in case of breakdown.

- The known alternatives “Indirect controls of GW use” (C1.1.2.3.2) and “Indirect controls of SW use” (C1.1.1.2.2) were considered as basic actions for the implementation of the more innovative policy alternatives. Providing more detailed information about the current situation would improve policy effectiveness. A key step would be the introduction of new institutional actors that could support the phase of gathering the above-mentioned information. Expansion of the two C-tree branches involves: (i) controls on the energetic consumption via the collaboration with the energy company; (ii) controls on the actual cultivated hectares and crop plans; (iii) introduction or re-organization of a dedicated institutional actor for the data set task. Furthermore, G3 suggested a combination of policy alternatives, including the declaration of the annual crop plan as fundamental constraint for the access to the SW distribution system. Similarly, “GW aquifers monitoring” (C1.1.2.3.1.4) was recognized a basic action for the implementation of other policy alternatives.
- The “Water resource production—Water transport from other Regions” was considered a well established alternative with several related technical and organizational issues. Several Regions neighbouring the Apuglia Region have a surplus of SW and this additional water volume is already used for the urban potable water distribution system. The participants underpinned that there is available knowledge on the topic but that this alternative has not been explored yet for the agricultural system due to political issues concerning specific institutional actors that were not involved in the process. Consequentially, the missing knowledge did not allow to expand the C-tree branch.
- Within a generic perspective, G2 suggested to explore the C-tree branch related to the alternative “Modifying the crop plan” (C.1.2.2). The economic subsidies driving the farmers’ tendency to prefer irrigation practices were proposed, i.e. an economic compensation for voluntary GW quantity monitoring and reduction of GW consumption. Participants suggested that this branch should be explored in detail thanks to the combination with a related K-space expansion (i.e. missing knowledge on the subject).
- Lastly, the alternative “Water resource production—Rainwater collection” (C.2.2.1) was pictured as an essential, even if limited, answer to the GW overexploitation problem. The collected rainfall represents a small volume, but this alternative combined with other options of water resources production (i.e. “Wastewater recycling”) could reduce the GW dependency of the agricultural sector. During the

discussion a new alternative was generated, and the group proposed to use rainwater and recycled wastewater for softening the seawater intrusion, increasing the GW quality. The rainfall collection practices were well known by the participants and they did not explore any discussion on the technical aspects.

It is worth underlining that the alternative "Water resource production—Water transport from other planets" (C.2.3.2.) represents a typical sample of innovative design through provocation. Thus, thanks to a successful generative phase where the C-space was explored without any constraints, participants proposed an alternative for increasing the quantity of available water, considering the presence of natural resources on other planets. The discussion during the 1-day generative workshop pointed out the lack of knowledge on technologies for universe exploration.

5.4 Evaluation of the Policy-KCP Tool

At the end of the process, a questionnaire on the advantages and disadvantages of the P-KCP participatory tool was distributed to all the participants, followed by detailed interviews. Participants have been asked to reply to open evaluation questions, namely, "Overall, what did you like about the P-KCP? Could you please describe strengths and weaknesses of the process proposed for the innovative design of policy alternatives?" The participants' answers helped the evaluation of the process for future improvement. Specifically, within the pilot case study, the methodology received positive feedback, e.g. "good the C-tree building activity", "open discussions", "useful the information exchange before the discussions and C-tree", "different points of view considered". The involved stakeholders considered the P-KCP an innovative and intriguing methodological approach since during the final discussion further innovative policy alternatives emerged (see Sect. 5.3). The highlighted advantages include the pre-workshop activities for eliciting and aligning the available knowledge on the policy problem under consideration (i.e. D- and K-phase). Furthermore, the K-phase and the preliminary C-tree were considered useful for structuring the discussion during the 1-day generative workshop, without influencing the stakeholders' opinion because it was mirroring their own point of view and partial K-spaces. Stakeholders appreciated the supplied information about the policy problem, with specific emphasis to the knowledge sharing sessions (i.e. K-sessions) and the definition of a shared problem understanding. They recognized that the P-KCP approach brought them at the same level during the discussions, in a more inclusive participatory perspective.

On the other side, the pinpointed disadvantages were mainly concerned the K-space building time-consuming activity and the 1-day workshop timeline. The majority of participants complained about the lack of time for continuing exploring the C-tree and for further discussions. Specifically, the experts considered the K-sessions long despite their recognition that the lack of stakeholders' availability was an important driver for the workshop organization decisions. Furthermore, one of the experts stated the need for a longer training on CK theory, in order to deeply understand the generative process. Lastly, few participants underlined the missing validation for the terminology used in the C-space.

6 Discussion

From a methodological point of view, the C–K theory framework and the P-KCP participatory tool offers a formal support for policy design, assisting the generation of innovative policy alternatives. In the presented policy design process based on C–K theory, it was possible to observe and formalize a "generative mechanism" aimed at modifying the stakeholders' values structure with the consequential expansion of the set of policy alternatives. It improved the quality of the participation process for the policy design and expanded its scope. This was achievable thanks to three main differences between the P-KCP participatory tool and other traditional participatory approaches (e.g. Creighton 2005; Majone 1993): (i) the alignment of different stakeholders' knowledge independently from the source in order to build a collective problem understanding and a shared concern; (ii) the assisted sharing of structured knowledge allowing the expansion of the available knowledge (i.e. K-space expansion) as a starting point for the unfixation process (i.e. C-space expansion); (iii) the methodological support for innovation management applied to policy design. We discuss these briefly in the following.

Firstly, the dichotomy between expert and local knowledge, characterizing the traditional participatory approaches, has been overcome thanks to the P-KCP participatory tool for the design of policy alternatives. Different knowledge subsets of the K-space have been aligned in a more inclusive participatory process. On one side, stakeholders are experts of the local policy issue and they offer a valuable insight for the problem formulation with a K-space expansion. On the other side, experts in several domains linked to the policy goal (e.g. technical, organizational, legislative expertise) facilitated the group learning process through the K- and C-space co-evolution. P-KCP aims to equally use each stakeholder's knowledge, in order to support the group generative mechanism for the innovative design of policy alternatives, enhancing a common problem understanding and improving engagement and consensus on the whole policy making process. New information not considered before has now become available.

Secondly, P-KCP re-establishes communication between stakeholders by unfixing the group from the dominant design, i.e. traditional and known policy alternatives. Fixation phenomena within the policy design process bring policy makers and stakeholders in conflicting and unsustainable situations. As it is possible to observe from the pilot case study, at the beginning of the 1-day generative workshop, participants tended to debate only about the dominant design, while at the end they were able to explore and expand more innovative branches of the C-tree with mutual consent, on both traditional and non-traditional solutions. Thus, the first part of the workshop leaded antagonistic stakeholders to discuss on the collected knowledge and to agree with the different problem formulations presented, allying their differences (see Sect. 5.1). Each participant realized the missing information and was more accommodating to new K-space expansions. This represented the starting point for stimulating discussions during the generative mechanism for the C-space exploration. Initially, the discussions were driven by conflicting situations due to knowledge limitations and fixation phenomena, while after the injection of new knowledge and the alignment of problem frames, they were more willing to cooperate in constructive debates. In addition, the injection of new knowledge related to non-traditional solutions (and provocations such as the alternative "Water resource production—Water transport from other planets") had positive effects on their collective activities and workshop results. Unfixed participants were available to propose new solutions or integrate known alternatives in a different perspective. Moreover, they were able to introduce useful knowledge K-space expansion) that became operational in the new alternative propositions C-space expansion) (see Sect. 3).

Lastly, P-KCP and the C–K theory framework provides a support for the innovative generation of policy alternatives. Traditional participatory approaches focus their efforts on the problem identification and the collective evaluation of known alternatives, following the dominant design. Several structured approaches such as Problem Structuring Methods drive the identification of known alternatives and not of the ones that are unimaginable. The generation of innovative policy alternatives is not considered and managed explicitly. In order to allow the emergence of unimaginable alternatives, a formal methodology for innovation management is needed. Under such perspectives, C–K theory and P-KCP represent the required guidance for a wider and inclusive policy design process.

Discussing the differences between P-KCP and KCP, the first one to note is the peculiar context in which we operate. With reference to the main features defining public policy, discussed in De Marchi et al. (2016), the KCP has been conceived and operationally validated in the private sector where innovation management is a central activity. Participants to KCP are generally incentivized to work together sharing the same company objectives and the only differences are between departments expertise and specific goals. Whereas, in public decision processes, the information is distributed, but not necessarily shared between different stakeholders with their own goals, backgrounds, expertise and knowledge bases. The lack of motivation to participate to the policy design process as well as of the willingness to change towards a more inclusive participatory approach are pivotal drivers of the policy making process.

Indeed, under a participatory decision making perspective, an effective policy design process requires the identification of a shared concern in order to motivate stakeholders' commitment. The P-KCP methodologically supports the participants for its identification. Generally antagonistic stakeholders are not motivated to work together, they have conflicting objectives, different values systems and distant personal perceptions of the same problem. Moreover, Kim and Mauborgne (1998) underlined that people tend to react more positively when treated with higher levels of "procedural justice". Ackermann and Heinzerling (2004) stated that the ability to capture, structure and analyse contributions from participants assists not only in ensuring that "procedural rationality" (Simon 1976) takes place but also that "procedural justice" is served (Kim and Mauborgne 1995), encouraging stakeholders to absorb a larger share of ownership for the outcomes, therefore increasing the likelihood of their implementation. A concept similar to the shared concern has been discussed in Ostanello and Tsoukiàs (1993), where the identification of the meta-object of the Interaction Space allows an integrated problem representation to be developed. In this regard, P-KCP builds a collective problem understanding allowing the stakeholders to motivate to participation. In case of stakeholders lacking proactive efforts and a shared concern, each stakeholder tends to think and discuss policy alternatives related only to their individual problem framing (i.e. fixation phenomenon). Building a collective problem formulation allows the activation of the design process while conflicting situations considering the individual perceptions causes clashes.

Secondly, in classical KCP participants are physically working in the same company, while stakeholders and institutional actors are often delocalised and have to interact from distance. The geographical constraint and the time limitation make the realization of the classical seminars for the K-space expansion difficult. During a KCP, each participant develops its own K-space and several seminars are developed in order to offer more knowledgeable guidance for the generative phase and the C-space evolution. Whereas, during a P-KCP process, the learning process within the K-phase is compressed because the K-space has been built by analysts. Stakeholders receive an initial set of alternatives and are required to discuss the starting point and explore it in order to support the C-space expansions. The design management team elicits and structures stakeholders' knowledge before the generative workshop due to the lack of engagement in the process and in the policy issues as well as the lack of skills in developing research activities in a systematic way. This represents an innovation in C–K theory based tools.

7 Conclusion

This paper presents a pilot application of an original approach for the innovative design of policy alternatives. P-KCP is a methodology formalizing the policy design process based on C–K theory. It supports the generation of unimaginable alternatives thanks to the co-evolution of the K- and C-spaces according to the C–K framework. It connects local and expert knowledge within the whole design process thanks to the construction of a collective problem understanding.

Mainstream policy analysis does not focus on the generation of novel policy alternatives and it is more effective in relation to the evaluation of known alternatives. Thus, participatory processes have been designed to facilitate the exchange of knowledge in order to develop more or less shared process of evaluation. The identification of traditional policy alternative (dominant design) is an ordinary process thanks to several approaches derived for instance from Problem Structuring Methods. For this reason, we suggest the use of a generative participatory process separated from the evaluative one, using a C–K theory based policy design tool.

The experiences carried out in the Apulia case study supported the application of the P-KCP participatory tool for the design of policy alternatives. It creates new insights and evidence. It brings together stakeholders, experts, institutional and non-institutional actors aiding them to find new ways of working together efficiently, generating innovative possible alternatives and encouraging longer term thinking.

P-KCP facilitates the transfer of knowledge, enabling participants to embed learning back into their organisations. As a result, we observe that policy design is a generative process for the creation of a new dimension of values, overtaking fixation phenomena through the creation of new variables and/or the elimination of variables without value for the process. For example, within the case study, we were able to introduce new alternatives in order to modify the value structures in a successful policy making process (i.e. from the dominant design alternatives such as the pricing strategy, to the innovative ones as the shared management of GW aquifers).

In conclusion, this work considers that the traditional participatory methodologies focus on how different stakeholders with different preferences and decisional criteria are going to decide together once design of alternatives is given. C–K theory, instead, offers a theoretical framework for an advanced participatory policy design process. Specifically, the P-KCP participatory tool, assists policy makers and stakeholders to work together for the generation of alternatives overcoming difficulties of the traditional approaches. The knowledge alignment represents the starting point for building a shared concern and breaking the fixation phenomena, toward a generative phase to go beyond known solutions.

We acknowledge our findings have some limitations, suggesting pathways for improvement. Firstly, the pilot case study offered several insights for improving the applied methodology and assuring its replicability. The positive results we obtained require further inquiry from different disciplines perspective, such as policy science. Secondly, a open challenge for the future is to demonstrate, thanks to a portfolio of case studies, that P-KCP can be used with any type of policy making process. Thirdly, for managing the P-KCP participatory tool, it is necessary to possess a theoretical understanding of the C–K framework: both the expertise, on the policy issue and on the process, are equally valuable for the success of the participatory activity. Fourthly, stakeholders engagement activities, the identification of the gatekeeper-stakeholder and the K-space building process have been time demanding, and further research is essential. Lastly, the issue of the policy design legitimacy has not been investigated in this paper and in general in participatory public decision making processes; a notable exception is Mazri (2007). The topic will be discussed and refined in a further development of this work.

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ASSESSING AND IMPROVING THE COVERAGE OF A STRATEGIC RESEARCH AGENDA: A DESIGN THEORY APPROACH

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ABSTRACT

Strategic Research Agendas (SRA) bring to the research community a prospective and collective vision of a sector and are intended to provide directions for future research efforts. However, some promising innovative areas are not always foreseen in those documents, which raises the question of the relevance and adequacy of their coverage. While engineering design is often considered to translate SRA guidelines into product development, we believe it can also be of great help regarding the design of an SRA. In this paper, we will first address how to assess the scope of an SRA through a framework based on C-K theory, before exploring how to extend it, if need be. To answer those questions, we will examine a high-quality roadmap: the Electronic Components and Systems Strategic Research Agenda (ECS SRA). Our resulting method will provide us the means to assess SRA coverage and to ensure that interesting research areas are not forgotten unintentionally, in order to allow to a further enrichment of the document if needed.

Keywords: Strategic Research Agenda, Evaluation, Design engineering, Design theory, C-K theory

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1 INTRODUCTION

Numerous Strategic Research Agendas (SRA's) and roadmaps have been widely introduced in different fields to support both Research & Innovation and business objectives (Barker and Smith, 1995). Through their structured insight of collective research priorities, they provide decision-makers with a clear understanding of a sector while identifying new opportunities or issues. Nevertheless, in some scientific domains, research efforts were proven to be concentrated in a limited number of areas (Agogué and Cassotti, 2012) and did not tackle all the possible desirable innovation options. As a result some agendas could miss some promising disruptive innovations. In this paper, we propose a methodology, based on a design framework, to diagnose whether there are interesting research areas that are not covered by Strategic Research Agendas (SRA). In addition, we describe how to identify non-stated concepts that could benefit from further investigation.

2 LITERATURE REVIEW AND RESEARCH QUESTIONS

The term Strategic Research Agenda (SRA) is widely and commonly used, but its distinctive character regarding the "roadmap" appellation stays imprecise. Even more so as there is no standard meaning or definition of what is covered by the designation of science and technology roadmaps (Lee and Park, 2005). Although they all share an extended look at the future of a chosen field of inquiry, and mobilize collective knowledge and imagination of drivers of change in the involved field (Galvin, 1998), many different types of roadmaps exist and have spread to diverse environments since their initial implementation (Willyard and McClees, 1997). Existing literature has attempted to classify them into various categories and conveniently SRA's echo some of Phaal and al. (2004) classifications such as text format and long-range planning. Therefore our definition of SRA's rely on those classifications and we consider an SRA as a text-based roadmap aiming at a strategic long-range collective vision of sectoral and multiorganizational environment, often designed to align national or international research endeavours. In that respect, SRA's define what are the priorities to be addressed collectively in a given research area, in order to gain knowledge and be able to tackle current and future issues, while extending the horizon of a domain. Furthermore, SRA's are sometimes the cornerstone for the calls for projects for different national or international funding programmes.

Literature has mainly considered the functions and uses of roadmaps, but rarely examines their assessment, as mentioned in the work of Robinson and Propp (2008). Actually, that kind of document can be evaluated according to varied requirements as the competence of the roadmap team, the relevance of stakeholders (Kostoff and Schaller, 2001), national priorities and many other criteria. In this article we will only focus on SRA assessment in terms of coverage, without taking into account other conditions. As a matter of fact, SRA's are supposed to focus on strategic collective priorities, and might not be entirely exhaustive in their coverage. Nevertheless, SRA writers must decide intentionally to omit some areas. In order to ensure the correct decisions are made, the widest possible coverage must be initially considered, without concentrating too much on a dominant design that encompasses the most commonly envisaged solutions for the ecosystem. The SRA elaboration process must foster a variety of potential paths in order to spur innovation, inspire the community and counterbalance the tendency of organisations to have restricted research horizons (Rosenberg, 1976). The resulting SRA will go beyond the path-dependency (David, 1985) of its source community and will complement it with a collection of promising paths creation (Garud & Karnoe, 2001) which aims to deviate from commonly considered solutions.

Along this line, some communities have considered design theories to assess rigorously the ability of actors to break those dominant designs, unveiling promising unidentified paths. They include Cogez and al. (2013) work using C-K theory (Hatchuel and Weil, 2009) to prove the good coverage of the International Technology Roadmap for Semiconductors (ITRS). Their methodology enabled them to depict and assess the different paths described in the roadmap. Moreover, in a design perspective, SRA's must clearly distinguish acquired knowledge from identified unknowns which are relevant to be investigated in the future. In that respect, our first research question will address how to diagnose whether there are interesting research areas that are unintentionally not covered by SRA, through a tool differentiating clearly what is presently known and what is still undiscovered.

Besides, such a method would be also useful to pilot exploration and propose additional relevant concepts to investigate. Indeed, C-K theory was also leveraged to build some referential frameworks allowing to distinguish unexplored pathways, leading to a potential enrichment of the research environment. This tool enabled Agogué and al. (2012) to unveil paths-in-the-unknown, only attainable through new innovation capabilities of involved actors. In that respect, our second research question will be how to create a method, that will allow the possibility to identify and investigate undiscovered promising innovation paths to potentially supplement an SRA, if need be? To answer those questions, we propose to develop a methodology based on a C-K framework leading to SRA coverage assessment and enrichment.

3 METHOD

We propose to analyse an SRA content, through a design framework inspired by C-K theory, transcribing the document content into a C-K referential diagram. Those C-K representations have been used in many studies as in the work of Cogez and al. (2011), Chen and al. (2017), Le Masson and al. (2017) or Vourc'h and al. (2018). However, this method must be adapted to our specific material, namely an SRA. Unlike previous studies, we do not have any initial concept to start with, but rather a text-based document, listing different topics and issues. SRA's are composed of numerous statements, paragraphs, often organized under sub-titles and major challenges in a chapter structure but may not distinguish clearly the concept space and the knowledge space defined in C-K theory. Hence, eventual reformulations may be needed to create proper conceptual formulations according to C-K theory definition. Those formulations are explicit concepts (ECi) as they refer to SRA explicit content, this is also the case for their related knowledge (EKi). Each title or bullet point is thus transcribed into an ECi, and SRA paragraphs are transcribed into local concept-tree composed of numerous ECi, while in the meantime their related knowledge is classified in a related basis.

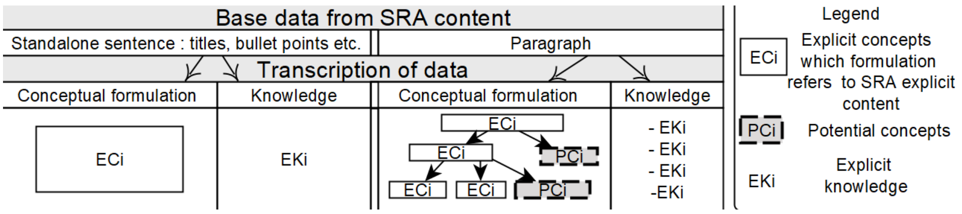

Figure 1. Method to transcribe SRA content into concepts and knowledge, while identifying the position of potential conceptual paths that are not covered by the document

In some situations, explicit concepts do not cover all the potential scope of a partition, and additional potential concepts (PCi) could be thus added in local trees. Those locations are clearly pinpointed during the transcription as such concepts prove that the document does not cover all the C-space. In order to have a broader analysis, we propose to collect all the ECi from standalone concepts or local trees and then, to arrange them into a general architecture, while the knowledge basis is structured into several pockets of knowledge, according to C-K theory principles. However, ECi's resulting from SRA's are very unlikely to arrange into a perfect concept tree, as the SRA structure is not built according to this pattern. That is why, to organize such a tree we look for implicit concepts (ICi), present in the underlying content of the SRA in order to create a coherent architecture. Those common concepts help to structure the conceptual tree while putting in evidence common points that are shared by SRA items, but not stated explicitly. They enable the creation of structured innovation pathways corresponding to the SRA content and to identify further uncovered areas (PCi). Exchanges with SRA contributors help to ensure the coherence of the resulting diagram with the SRA content.
As a second step, we incorporate further knowledge from experts to make the referential architecture more robust and potentially find relevant paths to investigate. This knowledge can come from SRA contributors, experts of the involved field or experts from other communities. To that effect, three different methods are developed in this study:

1. Investigating potential concepts (PCi) identified through partition completion during the transcription phase
2. Adding knowledge coming from various communities to ECS SRA Explicit Concepts (ECi)
3. Generating new concepts to complete the ECS SRA scope

4 MATERIAL

To apply our methodology, we looked for material written by numerous and highly qualified experts during a well-structured writing process. This document must deal with a very wide research scope and encompass diverse Technology Readiness Levels. We also sought a context where SRA authors were available to discuss with us the relevance of our approach. Thus, we chose to study the Electronic Components and Systems Strategic Research Agenda 2019 (ECS SRA) that spans the entire value chain of the electronics industry, covering Technology Readiness Level from 2 to 8, while setting out a single and common vision for Europe. Published by three European Industry associations AENEAS, ARTEMIS-IA and EPOSS and incorporating the work of over 200 experts across Europe, this document results from a regular writing process spread over a one-year period. Besides, most of authors were even more proficient as they were already familiar with roadmap writing process as those documents have been used in the electronic industry for many years. The first roadmap implementation was indeed conducted in Motorola (Willyard and McClees, 1997). Soon after the International Technology Roadmap for Semiconductor (ITRS) enterprise was launched, this time involving European actors. All those factors contribute a priori to create a very robust ECS SRA with the least possible bias. Besides, the ECS SRA is a cornerstone for the calls for projects of different European programmes such as ECSEL (Electronic Components and Systems for European Leadership) or EURIPIDES[2] and PENTA, which are EUREKA clusters. Since this document is used as a reference for project creation, we will use the mapping of project proposals onto the Concept-trees that we will have developed as a control tool of our methodology. Besides, as the ECS SRA is structured in 5 key application chapters and 5 essential capabilities chapters, we proposed, in order to have a better sample variety, to focus our study both on an application chapter, about Transport and Smart Mobility, and on an essential capabilities chapter, about ECS Process Technology, Equipment, Materials and Manufacturing. Each ECS SRA chapter is structured around several Major Challenges which will help us to articulate our analysis. One researcher was fully employed in the AENEAS Association for a period of 6 months to lead the study. This position allowed the researcher to work in strong interactions with both ECS SRA contributors and programme managers to ensure the elaboration of relevant diagrams and adequate project proposals positioning. Furthermore, it allows the possibility to have access to knowledge from several experts from different SRA scientific domains to constantly improve diagrams and enrich them.

5 ECS SRA ANALYSIS THROUGH C-K THEORY

5.1 Building a C-K roadmap diagnostic tool without any added knowledge

We apply the first steps of our methodology to the chosen application chapter of the ECS SRA using C-K theory, as illustrated in Figure 2. First, we will start our analysis with Major Challenge 3 and all of its content. Standalone sentences are eventually reformulated into concepts, without adding any further knowledge to keep as closely as possible to the ECS SRA structure, most of the time adding

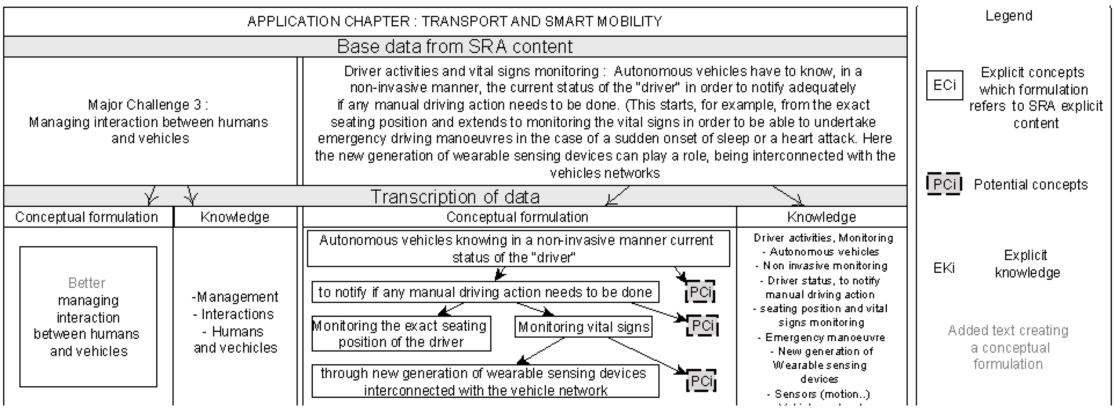

Figure 2. Example of ECS SRA transcription into concepts and knowledge at the sentence or paragraph level, revealing uncovered potential conceptual paths (PCi) in paragraphs

"better" to their initial formulation. Detailed paragraphs are transcribed into local trees of several ECi. It appears as first result that some uncovered potential paths (PCi) exist at the paragraph level since partitions are not complete with ECi according to C-K theory. Indeed, the first partition level deals with the transition between autonomous driving and manual driving. “To notify if any manual driving action needs to be done” is the only path stated in the paragraph. C-K theory helps us to identify that designing different desirable paths is possible here. Thinking of potential examples reveals other solutions are possible as autonomous driving is able to take the lead and substitute itself for manual driving. That is why the partition level is not complete and thus we position a PCi on the diagram to notify it. The second partition level is also restrictive although two different paths are proposed: “Monitoring the exact seating position of the driver” and “monitoring vital signs”. Nevertheless, other types of information could be of interest as the driver’s vigilance level. In some cases, the ECS SRA itself clearly mentions the existence of those potential concepts at a partition level, when detailing on one hand an example and stating on the other hand that some other paths could be explored without detailing much further.

Once we have translated all the Major Challenge content, we have to link the different resulting concepts. Indeed, Figure 2 does not show the link between “Managing interaction between humans and vehicles” and “Autonomous vehicles knowing in a non-invasive manner the current status of the driver” and the other transcribed concepts that are presented in Figure 3 as ECi. As it can be seen, we are able to organise the knowledge basis according to all the EKi fragments, but the links between different ECi are not described in the Major Challenge. That is why we need to resort to ICi to organise them as Figure 3 shows it. In Figure 3, the links are created at the level of the Major Challenge, but they can also be created at the level of the chapter as in Figure 4. An example of ICi from Major Challenge 3 is “through a better direct interaction with vehicles” which is a mother concept shared by all the Major Challenge ECi and can be seen at the top of Figure 3. As it is not the only path that we could think of, we position PCi to indicate potential additional partitions could be found at a later stage. ICi could be added at any partition levels and they shed light on paths that were potentially unconsciously chosen by roadmap contributors.

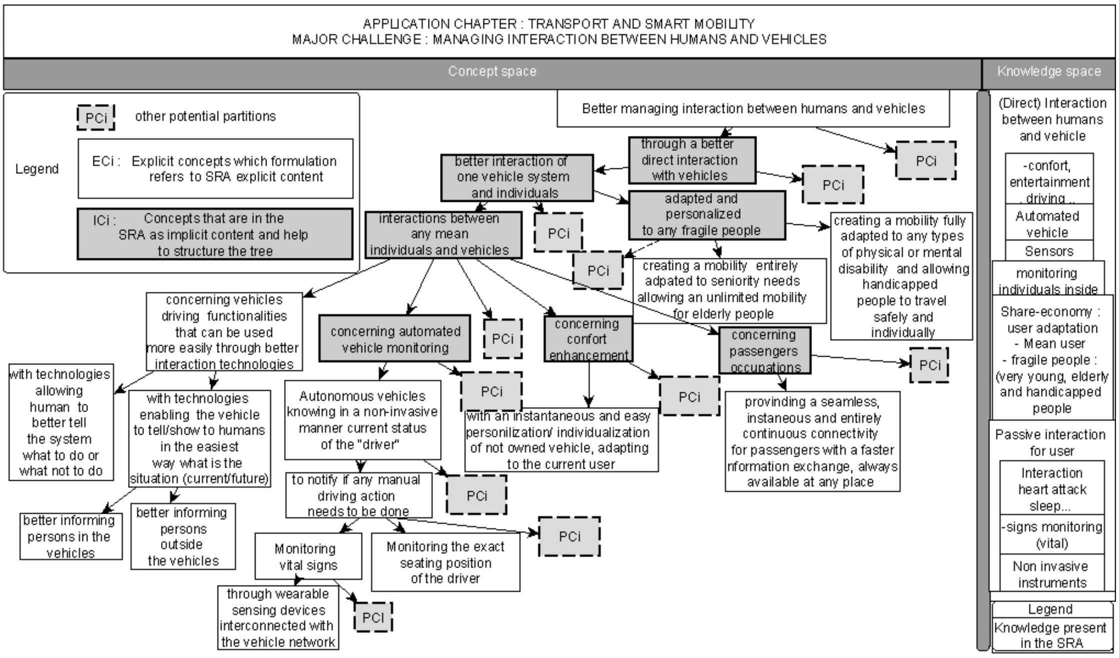

Figure 3. Creating a general concept-tree structure using ECS SRA ICi, revealing additional PCi not covered by the ECS SRA at the Major Challenge level

Regarding the ECS SRA chapter about ECS Process Technology, Equipment, Materials and Manufacturing, identification of innovation fields that are not present in the ECS SRA, was harder than for the application chapter about Transport and Smart Mobility. The text displays a structure which more closely reflects C-K like partitions, and the tree architecture is quite entirely described in the document. As illustrated in Figure 4 which compares the two studied chapter structures, the ECS SRA presents a disparity among its chapters, according to C-K theory.

Finally, to answer our first research question, this methodology allows us to pinpoint clearly where covered research areas are, and where some uncovered paths (PCi) are, in order to diagnose through discussion with ECS SRA contributors whether some innovative paths are not covered unintentionally. It appears the ECS SRA displays uncovered paths at the paragraph and major challenges level but also at the chapter level. Furthermore, the studied chapters present a disparity of transcription into C-K diagram.

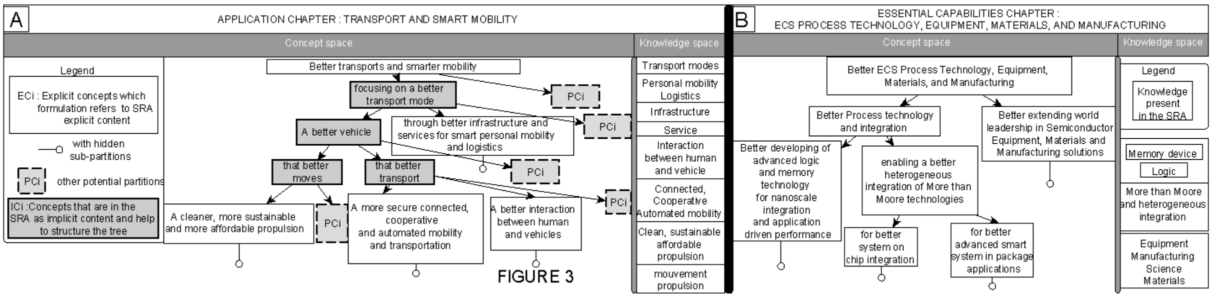

Figure 4. Heterogeneity of ECS SRA chapters: Each diagram represents an entire chapter where Major Challenges are transcribed into ECi. (A) The concept-tree structure elaboration of “Transport and Smart Mobility” chapter requires the use of ICi. (B) In contrast, the concept-tree structure elaboration of “ECS Process Technology, Equipment, Materials and Manufacturing” does not need to introduce implicit concepts as the explicit content of this chapter almost already constitutes a partition.

This study allows us to propose some guidance to the writing process of a Strategic Research Agenda. When first analysing the ECS SRA structure, we understood that the bullet points structure of the ECS SRA answered well all the diverse constraints of its elaboration. However, this highly condensed content, constituting a major part of the ECS SRA is not formulated with concepts. Instead, concepts which are present in the ECS SRA without needing any reformulation, are situated at a very detailed level, most of the time in paragraphs. Listed research questions do not bring to light what the current factors hampering innovation are, which would transform a topic into a concept, according to C-K theory. That is related to the fact that very little knowledge is explicitly mentioned in the document, preventing a layman to identify clearly what is the implicit concept under a classification title such as “managing interaction between humans and vehicles”. However, a scientific expert from this field can identify what is the related implicit knowledge of a topic and can transform it into a concept. Making explicit conceptual models used by experts while writing the document, would enable the reader to link the various listed elements. It would allow the possibility of better identifying consciously all the partition levels and concepts between sentence and paragraphs, in order to choose deliberately the most relevant coverage. Secondly, formulating the ECS SRA with more problem-oriented sentences and conceptual formulation rather than stating research questions would enable to explicit precisely current issues and address them through a wider scope of solutions. The goal is to prevent the ECS SRA focusing either on a hype subject or a dominant design, but rather systematically generating different approaches. Moreover, it was noted earlier that the ECS SRA sometimes used examples to explicit concepts. Using expansive examples (Agogué and al, 2014), modifying the object identity by adding unexpected attributes, help to generate non-intuitive pathways. Recent experiments based on a cognitive perspective showed these kind of examples significantly increase the resistance to fixation (Agogué and Cassotti, 2012) and must open more easily the pathway to potential additional concepts. This suggests that using expansive examples in an SRA elaboration could be an effective way to avoid fixation effects and increase the overall coverage.

5.2 Adding knowledge to build more robust trees and enrich the ECS SRA scope

To build a more robust tree, we include additional knowledge to our SRA raw transcription. Through this approach, we investigate, with different methodologies, how to enrich the ECS SRA scope.

5.2.1 Investigating potential concepts (PCi) through logical rules

First, we consider areas previously identified as potential concepts (PCi). New concepts are created through logical rules applied on surrounding explicit or implicit concepts sharing the same partition level. As an example, the new concept “better indirect interaction with vehicles” completes the partition level of the ICi: "better direct interaction with vehicles" using a complementary concept as presented in Figure 5. Such logical operations help new concepts to differentiate from the dominant design and potential new knowledge from external community may be needed to understand their implications. Thanks to this methodology, several different types of concepts are discovered. In the first place, new concepts (A) that are not present at all in the ECS SRA are created, as it is the case of our previous example. Some other concepts created through that approach are present in other ECS SRA chapters (B), which proves their relevance. Lastly, some concepts appear to be indirectly present in the ECS SRA (C). Indeed, at least one of their mother concepts, as well as some concepts from the same partition level, are ECi, but they are not themselves explicitly formulated in the document. Since the ECS SRA is intended as a guidance for project proposals, a way to control the relevance of the addition of such concepts, apart from their alignment with other ECS SRA chapters content, is to map project proposals on the concept-tree.

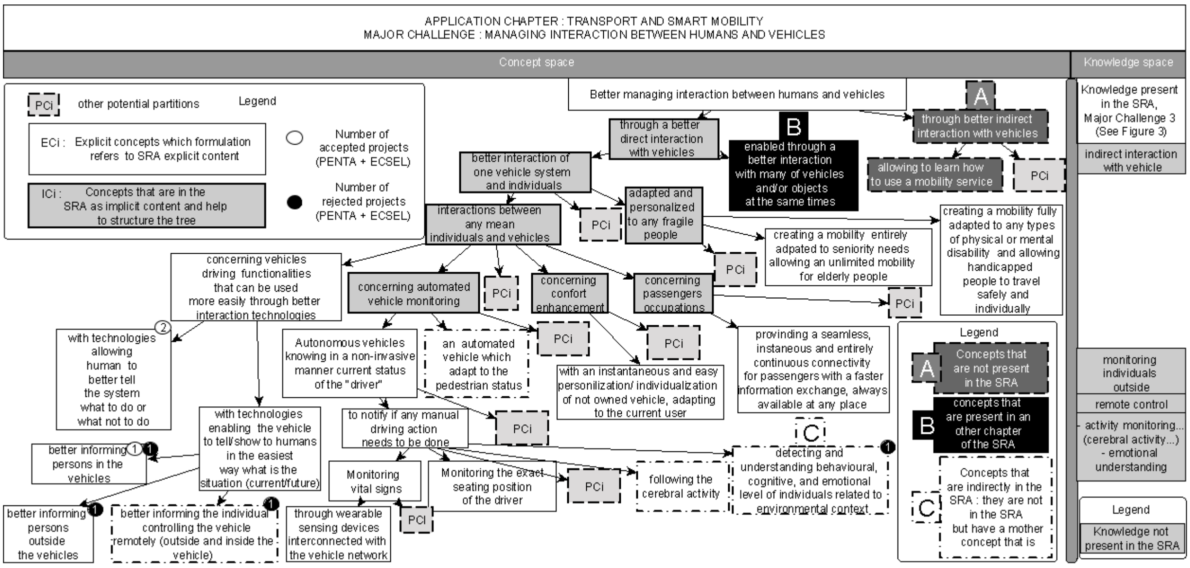

Figure 5. New concepts identification through PCi, using logical rules on ECi or ICi: (A) Identification of new concepts, not present in the ECS SRA (B) Identification of concepts present in other ECS SRA chapters (C) Identification of concepts indirectly present in the ECS SRA as they are not mentioned explicitly but at least one of their mother concepts is cited in the document as well as some concepts from the same partition level.

To test our diagrams, we map, onto the concepts-tree, projects proposals addressing the common subject-matter. Indeed, as was previously said, the ECS SRA is a cornerstone for the calls for projects of different programmes. Project proposals submitted to those programmes are considered through their publishable summary or project outline where their major concept often emerges. Then, projects are positioned on the concept-tree according to their central concept, as presented in Figure 5, where we make the additional distinction between funded and non-funded project proposals. For instance, we reviewed 92 projects proposals from ECSEL and PENTA programmes dealing with ECS Process Technology, Equipment, Materials and Manufacturing and 54 projects proposals dealing with Transport and Smart Mobility. Our interactions with members from ECSEL and PENTA allowed us to position correctly the different project proposals. Those projects are well scattered on the conceptual map in Figure 5. As a matter of fact, some of those projects are addressing our added concepts, which proves those concepts are relevant to the ECS SRA scope.

5.2.2 *Adding knowledge coming from various communities to Explicit Concepts (ECi)*

Another methodology consists in adding knowledge to an explicit concept. For instance, we look for additional knowledge on mobility coming from external communities, to tackle the chapter concept "ECS allowing better Transport and Smarter Mobility". The work of Amar (2018) is taken as a knowledge and conceptual resource for this chapter as it is a prospective view of mobility. Other experts are also consulted, and they reveal the importance of the multimodal aspect of mobility which is explored as a new concept. Indeed, they propose some paths to investigate it in Figure 6, which are compared later to the ECS SRA content. It appears that the ECS SRA mainly focuses on objects, and specifically on vehicle automation enabling future multimodality. For instance, mutualisation and synergy between objects are not addressed in the ECS SRA document. Nevertheless, some actors proposed project proposals addressing those concepts which proves the relevance of such investigations and may help to better structure diagrams following ECS SRA structure. Regarding the technical chapter about ECS Process Technology, Equipment, Materials and Manufacturing, we benefited from organized knowledge from different sources like ITRS and IRDS. In fact, those sources did not help to find disruptive branches while ITRS was proven to be of good coverage (Cogez and al, 2011, 2013).

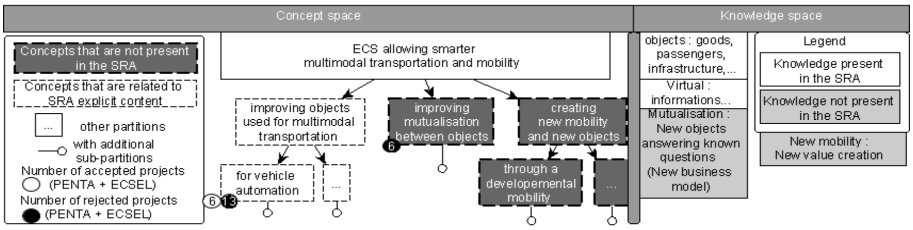

Figure 6. Exploration of the concept" ECS allowing smarter multimodal transportation and mobility". This concept that is not present in the Transport and Smart Mobility chapter was determined through added knowledge coming from external communities

This confirms that the ECS SRA technical chapter displays a large coverage which overlaps ITRS and IRDS content. However, this knowledge helps us to create a more structured knowledge basis allowing us to reorganize the global tree at the chapter level with partitions following C-K theory criteria, as shown in Figure 7. Thus, this added knowledge allows us to better structure in terms of diagram the chapter content, enabling a wider vision of the chapter landscape and the projects distribution, while highlighting the ECS SRA uncovered areas that would be relevant to investigate further.

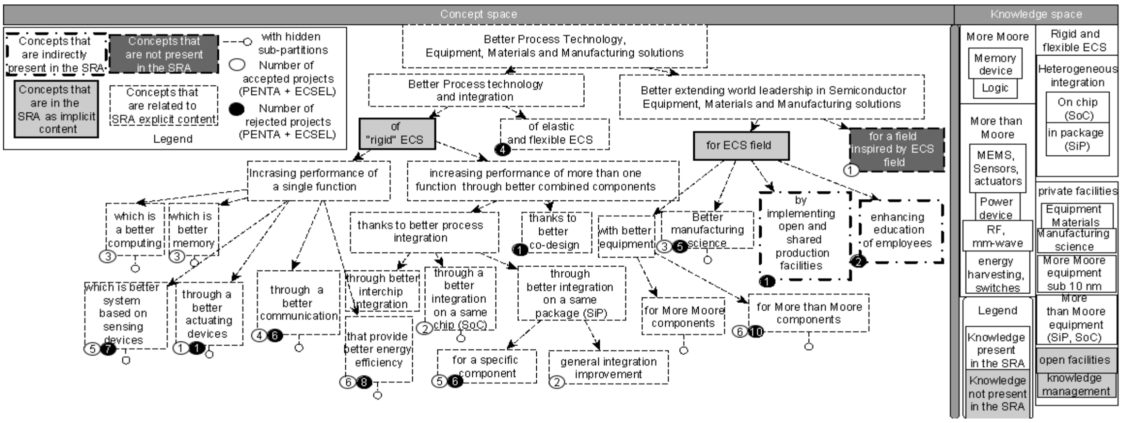

Figure 7. Excerpt from the ECS SRA referential diagram of the technical chapter including identification of uncovered areas and project proposals distribution.

5.2.3 Generating new concepts to complete the ECS SRA scope

The last approach consists in using knowledge of the ECS SRA to generate new concepts. So far, we considered actors as neutral in our study. Nevertheless, the fact that the ECS SRA is the basis for funding decisions of European collaborative research projects plays a great role in its content. But this aspect does not necessarily contribute to generate new desirable concepts. Thus, we proposed to use this strategic knowledge to force the generation of such concepts like for example "Memory devices suited for Artificial Intelligence needs and for which manufacturing can be brought back to Europe". The European dimension is here used to generate new concepts aligned with the ECS SRA goal, which could then be explored through C-K theory. Thus, this method help us to explore concepts out of the dominant design. The exploration of such a concept through C-K theory in Figure 8, highlighted the need to merge knowledge from different ECS SRA chapters which may explain they are not present in the current document.

To conclude, we investigated three different methods to identify and explore uncovered innovation paths that are not in the dominant design of the field. For that we use additional knowledge coming from internal or external experts. Those concepts can eventually be themselves explored through C-K theory, potentially involving experts from various communities. The relevance of such concepts was then verified through the mapping of projects proposals proving some actors consider those paths to be of interest. Besides, this mapping could prove useful to manage project portfolios of collaborative projects as Figure 7 shows.

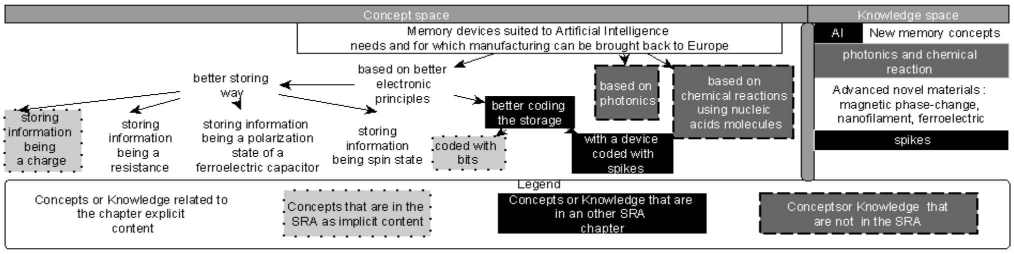

Figure 8. Exploration of a new concept merging knowledge from several ECS SRA chapters

6 CONTRIBUTION AND DISCUSSION

Our methodology, based on a C-K framework, provided us with the ability to diagnose whether there are some unintentionally uncovered areas in SRA. Discussion with experts allowed us to prove the relevance of our methodology, and then to identify new value-added innovation areas, that were not mentioned in the document, in order to enlarge its scope. Project proposal mapping confirmed the adequacy of newly identified innovation paths. Thus, this work provides support to make more explicit strategic decisions made on SRA selected coverage.

However, despite the sample variety and quality of our material, further researches, including a design framework, are needed on distinctive SRA. Indeed, it is the technology forecasting literature which is mostly interested in the elaboration process of agendas. On the contrary, instead of being used to create SRA guidelines, engineering design usually deals with SRA topics once they have been defined. Nevertheless, the establishment of such strategies requires a design effort in order to formulate correctly the technology directions. Today, we believe engineering design can tackle those questions related to SRA elaboration and scope. For instance, it could contribute to increase the relevant coverage of an SRA, revealing a tool that manages the risks linked to unidentified innovation paths and supports collective action aiming exploration of promising innovations. Few studies (Cogez and al, 2013) have implemented design approaches on roadmaps assessment, and we first pave the way to SRA analysis. But our approach also echoes more general aspects of research and the way design theory could help to consider formulation of calls for projects in order to spur more innovative solutions as well as the way to manage scientific portfolio through conceptual maps, for instance.

This work also reveals its usefulness for various kind of actors which raises the question of its implementation as a service in different contexts. Table 1 presents a variety of services using this methodology which could be offered to different types of clients.

Table 1. Services that could be provided based on the methodologies of this study

CLIENTS	SRA contributors	Project evaluators	Potential consortiums	Existing consortiums	Funding programmes	Public Authorities
OUTPUTS	- Proposition of new methodologies for chapter elaboration - Explicit the selected SRA coverage	- Suggesting improvements in proposal scope and/or constitution membership	- Exploration to extend the use cases and application domains of a proposed concept - Identification of potential partners	- Promoting further the project after its end through diverse explorations	- SRA referential map with projects distribution	- SRA referential map with projects distribution of the considered country/ Europe

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The Role of a Learning Approach in Building an Interorganizational Network Aiming for Collaborative Innovation

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Abstract
Collaboration has become a common way for organizational actors to engage in problem solving and innovation. Yet shifting from strategic interactions (driven by reduction of transaction costs) to transformational interaction (driven by collaborative transorganizational development) appears to be difficult to achieve in practice in a network setting. This article argues that such a shift can be enhanced by adopting an action learning approach, which entails working on real-life problems without clear solutions and collectively working to resolve them. Based on an action learning research process, this article therefore explores ways to support collective knowledge creation within an interorganizational network setting. It provides rich illustrations of how the interactions in the network changed through the process, and the participants moved from a space of territorial protection to a space for collaborative exploration. From this case, the article outlines a model for learning in interorganizational networks and discusses related challenges.

Keywords
action learning research, innovation, interorganizational collaboration, network learning, knowledge creation, knowledge–concept–proposal (KCP)

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Introduction

With increased demand for complex innovation and with a more distributed world, connecting across boundaries becomes a key organizing mechanism for innovation and hence organizational actors increasingly engage in co-creating solutions and experiences (Keys & Malnight, 2012) with actors from other organizations. This implies a shift from firm-centric innovation to network-centric innovation (Coughlan & Coghlan, 2011), acknowledging interorganizational collaboration as "networks of relationships" (Sharma & Kearins, 2011). For some organizations, network-centric innovation is a matter of survival and is necessary to stay in business. Accordingly, interorganizational relationships and the capability of firms to learn and draw from the knowledge shared by the different parties within the network become critical when facing rising and multifaceted demands (Chesbrough, 2003; Fryxell, Dooley, & Vryza, 2002; Inkpen & Li, 1999). It could be argued that working collaboratively across not only organizational but also sectoral and national boundaries to achieve "collaborative advantage" (Huxham, 1996) is now a common component in organizational life.

How to interact successfully under such complex circumstances to create innovation remains a practical challenge for many interorganizational arrangements such as alliances, networks, ecosystems, and platforms. Directing the attention to action and the practical doing of innovation includes the collective practice of organizational learning (Revans, 1971) and network or interorganizational learning (Coughlan & Coghlan, 2011). To exploit the advantages of inter-organizational learning *members committed to both taking action and learning*, a *questioning and reflective process* and a *facilitator* are needed (Coghlan & Coughlan, 2015). In other words, shared innovation processes and the learning they entail need to be managed and supported (Bergman, Jantunen, & Saksa, 2009; Buckley & Carter, 2002; Chesbrough & Teece, 2002) in order to enable a transition from a strategic to a transformational network (Coghlan & Coughlan, 2015). By strategic we infer that the focus of the interorganizational collaboration is on the economics of achieving greater efficiencies. By learning and transformational we mean conditions where a network learns as a system and adopts the transformation of its participating firms. Such a transition implies encouraging and facilitating an open flow of knowledge that fuel innovation and action learning in which all participants can benefit. However, to this date, few studies have been conducted to explore how to enable this shift, and this warrants further exploration from both a theoretical and practical point of view.

In this article, our particular focus is on the interactions in an interorganizational network setting where members of different organizations engage in collective knowledge creation as peers (Elmquist, Ollila, & Yström, 2016). We build on an action learning research process involving three of the authors working together with participants in a collective knowledge creation initiative, a kind of temporary and formal network in the automotive industry, with the purpose of facilitating a joint grant application process for public funding in collaborative innovation among six organizations exploring the boundary conditions of automated vehicles in a future transportation system.

The focus of the action learning research was on how to enable the interaction between the participants to transition from an initial hesitant mind-set to a sharing, trusting and explorative one in order to achieve the ambitions set out in the network. In designing the research, we used a design-based management tool for innovation, that is, the knowledge–concept–proposal (KCP) method (Elmquist & Segrestin, 2009; Hatchuel, Le Masson, & Weil, 2009) to invite the participants to engage in collective learning. The question underpinning the article is: How can a learning approach support collective knowledge creation in an interorganizational setting aiming for collaborative innovation?

A considerable amount of data was generated, and this article gives rich accounts of the process in which the action learning researchers were involved. We draw on theories on network action learning (Coghlan & Coughlan, 2015; Coughlan & Coghlan, 2011) to outline a model for learning in interorganizational network settings which explicates the transition process of the interaction from a strategic logic to a transformational one. Thus, the article makes a theoretical and a practical contribution to our current understanding of network learning and how to support collective knowledge creation from an organizational and managerial point of view.

Collaboration Challenges in Interorganizational Network Settings

Opening up the organizational boundaries to collaborate with others has become unavoidable in the search for creative outcomes to innovation problems. There is a range of possibilities for designing relationships with other organizations, including alliances, networks, communities, and platforms (West, 2014). Dyer and Singh (1998) suggest that a firm's critical resources span firm boundaries and are embedded in interfirm routines and processes.

The concept of network competence stresses collaborative aspects and social qualifications such as ease of communication and reliability (Ritter & Gemünden, 2003; Ritter, Wilkinson, & Johnston, 2002). However, networks are generally not under the control of an individual firm but are more of self-organizing systems in which order emerges from the local interactions taking place (Wilkinson & Young, 2002). Indeed, interorganizational collaboration in networks can be challenging as it does not involve the use of control through legitimate authority (Lawrence, Phillips, & Hardy, 1999; Ouchi, 1980).

Besides, the more individuals and organizations are interacting, the more complex the aims and expectations become (Håkansson & Snehota, 1995). Thus, system boundaries are mostly unclear and actor preferences are both heterogeneous and evolving, leading to troubles in creating collective action (Huxham & Vangen, 2004). The goals and the purpose for the collaboration are thus continually moving targets (Rindova & Kotha, 2001), making best practices and contextual knowledge that build common ground and support coordination more difficult to share (Orlikowski, 2002). The ability to reflect upon and even contest meanings or uses may therefore be lacking (Levina, 2005), and the production of new practices or solutions through joint sensemaking

Table 1. Theoretical Background: A Selection of the Challenges Identified in Interorganizational Collaboration.

Challenges	Description	References (partial)
No legitimate authority	Not under the control of one individual firm	Lawrence, Phillips, and Hardy (1999); Ouchi (1980)
Unclear system boundaries	The scope of the collaboration is changing	Huxham and Vangen (2004); Rindova and Kotha (2001)
Self-organizing system	Order emerges from the local interactions taking place	Wilkinson and Young (2002)
Actor preferences heterogeneous	Hard to build common ground and joint collective action	Huxham and Vangen (2004); Håkansson and Snehota (1995); Orlikowski (2002)
Network competence lacking	Social qualifications such as ease of communication and reliability	Ritter and Gemünden (2003); Ritter, Wilkinson, and Johnston (2002)
Joint sensemaking lacking	Ability to reflect upon and contest meaning	Hardy, Lawrence, and Grant. (2005); Levina (2005)

among different collaborators becomes problematic (Hardy, Lawrence, & Grant, 2005). Fayard and Metiu (2014) argue that challenges of this kind are dialogical in nature and require recurring exchanges and learning among collaborators to be overcome. Complicated and slow decision-making processes can make the collaborative work tedious, and a realization that all partners are not working toward the same goal can make them lose faith in what they are doing. A summary of identified challenges in interorganizational collaboration is presented in Table 1.

When organizations are part of a pattern of multiple alliances, these alliances can be considered as a network of interorganizational interaction (Gomes-Casseres, 1996; Powell, 1990). Organizations in a network may work together to create value through coordinated efforts, particularly, in the presence of network effects. Docherty, Huzzard, de Leede, and Totterdill (2003) characterize three types of networks: strategic, learning, and transformational. The purpose of a strategic network is the reduction of transaction costs and the strategic network may operate and suffice for the duration of a contract with limited trust and guarded interactions. The purpose of the learning network is learning through exchanges of experience and the transformational network has the purpose of collaborative transorganizational development beyond the immediacy of current orders and contracts. Accordingly, it can be argued that to mitigate challenges in interorganizational collaboration aiming for collective innovation with the uncertainty and ambiguity it implies, a transformational network is needed. In this article, we build on the extant theories on challenges in interorganizational collaboration presented and introduce a learning perspective guiding our inquiry on how these challenges can be mitigated and how collective knowledge creation in an interorganizational network setting aiming for collaborative innovation can be supported.

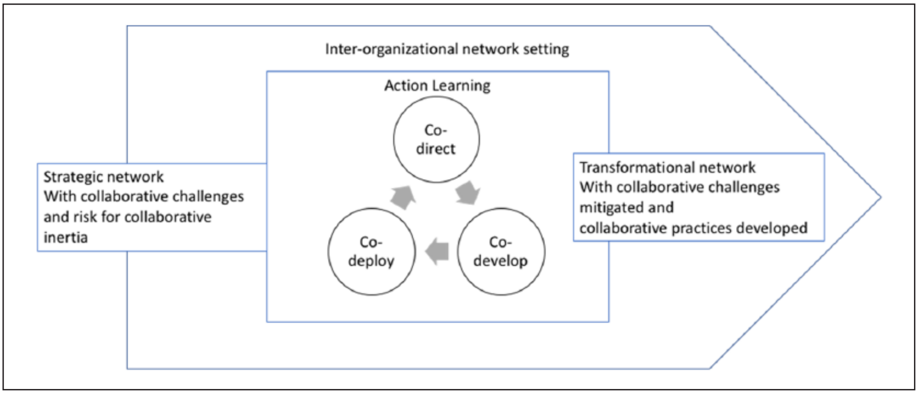

Figure 1. A framework guiding the inquiry of how to support collective knowledge creation in an interorganizational setting.

A Learning Perspective

Action learning is considered an approach that enables an interorganizational collaboration to move from a strategic to a transformational mode of relating, and at the same time allows for researching that same process. While it is a term with many meanings, Coghlan and Coughlan (2015) argue that in essence, action learning is about participants working on real-life problems that do not appear to have clear solutions, and that participants meet on equal terms to report to one another and to discuss their problems and make progress in addressing them. Coughlan and Coghlan (2011) make the case that adopting an action learning approach enables networks to learn.

Network action learning is characterized by peer engagement in exploring and learning from addressing real issues in the network. Coughlan and Coghlan (2011) show how the continuous improvement process of direct, develop, and deploy in the firm (Slack & Lewis, 2008) becomes a collaborative improvement process of co-direct, co-develop, and co-deploy in the network. They demonstrate that action learning enables networks to develop from being strategic to becoming learning and transformational. They conclude that the adoption of an action learning approach, which entails the commitments to action and to learning, enacted through a questioning and reflective process based on operational data, enables the collaborative action and associated learning which underpins the transition to a transformational network (Coghlan & Coughlan, 2015).

In this article, we use the action learning framework of co-directing, co-developing, and co-deploying by Coghlan and Coughlan (2015). Based on this framework we consider learning to be a continuous circular process (see Figure 1) and we use the framework to analyze a case of interorganizational collaboration.

Methodology

Research Design

This article is based on action learning research, a research design belonging to the family of action-oriented approaches to inquiry (Coghlan & Rigg, 2012; Coghlan & Coughlan, 2015; Coughlan & Coghlan, 2011). Action learning research operates in the space of practical knowing, where concern is for the practical. It shares the distinctive characteristic of all action-oriented approaches as it addresses the twin tasks of bringing about change in organizations and in generating robust, actionable knowledge, in an evolving process that is undertaken in a spirit of collaboration and co-inquiry, whereby research is constructed *with* people, rather than *on* or *for* them. The quality of the action learning research processes is grounded in the dual focus on both the inquiry process and the implementation process. Action learning research provides a basis for critical inquiry as it generates awareness and understanding of tensions, contradictions, power dynamics between organizations (Coughlan & Coghlan, 2011; Rigg & Trehan, 2004; Vince, 2004). It operates in the people-in-systems domain and applied behavioral and organizational science knowledge is both engaged in and drawn on.

The action learning research this article is based on focused empirically on a collective knowledge creation initiative, which can be characterized as a kind of temporary and formal network in the automotive industry. The research included action learning processes where three of the authors worked together with network participants and engaged in peer conversations that were based on the shared commitments to action and to learning and enacted through a questioning and reflective process about the emergent experiential and operational data. This provided a rich methodology and methods for the action research. We used a specific method called KCP to guide the learning process. A detailed description of the method is provided after a brief introduction of the empirical context.

The Empirical Context: The ABC Network

The ABC network, initiated in 2013, is set in the automotive industry in Northern Europe, where it has become increasingly more common to engage in networks and interorganizational projects of different forms (Ili, Albers, & Miller, 2010; Segrestin, 2005; Yström, 2013). The network had been formed as a result of a mutual interest in the development of automated vehicles, a crucial area for the partners involved and the future of the industry. Previous attempts by the organizations to individually receive funding had been unsuccessful, and the public funding agency had required that they submit a joint application. Therefore, the collective knowledge creation network involved six partners including large (competing) automotive companies such as AB Volvo, Autoliv, Scania, and Volvo Cars and was initiated by the vehicle and traffic safety center SAFER. SAFER is an association of companies such as AB Volvo, Autoliv, government agencies such as the Swedish Transport Administration, smaller technical consultancy companies, and universities such as Chalmers, the Royal Institute of Technology (KTH) and Gothenburg University, focusing on improving road safety.

Three individuals from a research institute were asked to form the management team of the network. It had been reported that the network experienced difficulties early on in defining a joint platform and a joint purpose. In an effort to tackle this challenge, the researchers were asked to participate as part of an action research process that could help the work to move forward. Three authors therefore started working in collaboration with these three managers in 2013. The managers were indeed eager to develop and test a method involving the participants that could increase the possibility of creating sustainable and utilizable results. Thus, this study was driven by an actual need and interest from practitioners to change something in their practice (Eden & Huxham, 1996).

Supporting the Learning Using a Tool for Collaborative Innovation: The KCP Method

To support the learning in the action learning research process, the researchers proposed applying the KCP method, which aims to organize innovative capabilities distributed among a large collective. Based on a theoretical framework from engineering design labeled "C-K theory" (Hatchuel, 2002; Hatchuel & Weil, 2009; Le Masson, Weil, & Hatchuel, 2010), the method was originally developed in collaboration with RATP, the public transport operator for the city of Paris. Since 2003, more than 60 KCPs have taken place in a range of companies in various contexts, within and outside France (Agogué & Kazakçi, 2014). A KCP method is typically carried out in three phases, each demarked by at least one workshop with invited participants (see Table 2).

A team consisting of managers from the organization and external KCP-consultants or researchers usually organizes the setup of the KCP and guides the emergence of new knowledge and new ideas. Each phase necessitates iteration and reflection before moving into the next phase. The method is said to provide means to identify innovative value spaces that enable the development of innovative capabilities, the integration of both internal and external knowledge, the development of learning paths, and the identification of external collaborations (Elmquist & Segrestin, 2009). In the specific context of the ABC network, 15 to 20 participants from the six partner organizations and with primarily engineering backgrounds were involved in a series of workshops.

Data Collection and Analysis

The action learning research process that took place in the initial phase of the ABC network covering a period of approximately 18 months, comprised four steps and multiple sources of data, including numerous conversations and e-mailing with managers over a period of 18 months, 16 interviews with KCP experts and users, observations of three full-day workshops completed with field notes, an open-question survey post-workshop, as well as written documents produced by the managers over the whole period.

To analyze the data for the theoretical contribution, a grounded theory strategy advocated by Langley (1999) was followed. Data were continuously compared with

Table 2. Outline of Phases in the KCP (Knowledge–Concept–Proposal) Method.

Phases	K phase	C phase	P phase
Overall aim	• Mobilization of existing knowledge • Acquisition of new knowledge	• Formulating concepts and create workshops around disruptive ideas	• Developing a design strategy • Proposing roadmaps
Description	Expanding the common knowledge among the collective (including knowledge from outside the field); the aim of the phase is to enable different actors to share not only existing knowledge from different expertise from inside and outside the firm (i.e., to share the state-of-the-art) but also pending questions and exploratory issues (i.e., to share the state-of-the-non-art)	Team work around conceptual propositions aiming at providing a large number of creative ideas and building on the knowledge exchange from the first phase; this second phase is a set of creative workshops where usual creativity techniques are used to help participants to discuss strange propositions, crazy concepts. These initial concepts are chosen to be quite generative so that teamwork is useful to explore them in different ways, leading to the emergence of a variety of refined and elaborated ideas	Building on discovered new knowledge and explored new ideas, the aim of the P-phase is to elaborate proposals, projects, perspectives to implement and nurture novel propositions within the firm. It is usually associated with discussions regarding internal organizational issues but also regularly leads to renegotiating the nature of the relationship of the firm with the rest of its ecosystem. This phase usually requires the longest preparation

the emerging theoretical insights (Glaser & Strauss, 1967). Since the research process was longitudinal it was possible to use a process approach to theorization (Langley, 1999) to depict the nature of the collaboration in relation to the phases in the KCP method and the various steps of the research process. Open coding (Strauss & Corbin, 2008) and memoing (Charmaz, 2014) was used to label raw data and these where discussed by the authors several times to record emergent hypotheses and synthesize the inductive findings. Table 3 presents an overview of the different steps in the action learning research process including data collection, main activities, and the questions intriguing the researchers and management.

Findings: A Learning Approach Supporting Collective Knowledge Creation

Already in the initiation of the action learning research project, a multitude of challenges associated with collaboration, which had been an obstacle for innovation and previous attempts to collaborate around automated vehicles, were articulated by the

Table 3. Overview of the Steps, Main Events, and the Intriguing Questions in the Action Learning Research Project.

Steps in action learning research project	Sources of data collection	Phase of KCP process	Main activity	Issues and challenges
Codirecting	• Nine semistructured interviews with users and developers of KCP (2011) • Conversation with project management on open innovation challenges (2013) • Semistructured interviews with CK-theory/KCP experts on adapting KCP to open innovation (2013) • Field notes from initial workshop presentation at Traffic System Competence Group (2013) • Document analysis of ABC project proposal/funding application (2013)	• Preparation phase (October 2011–March 2013)	• Inquiring into the KCP process by interviewing and discussing with users and developers of the KCP process in France • Convening with French researcher on using the KCP process as an intervention in an open innovation context	How is the KCP process operating and why? What are the underlying mechanisms? How could a method developed to enhance innovation within a firm be used to enhance innovation in a multi-actor context?
Codeveloping	• Six meetings with ABC Management team (2013)	• Invitation phase (March–May 2013)	• Presenting the KCP process to the ABC project management	The role of the researchers when doing intervention research? The role of the project management? How to bridge the competitive relationships of the participants? How to secure active participation and engagement of a wider group?
	• 45 Hours of e-mailing and phone-calling (2013)		• Dialoguing about and planning the setup of the three workshops including different roles • Discussing whom to invite and how to formulate the invitation	
Codeploying	• Three full-day workshops with ABC project members (2013-2014)	• Knowledge phase (August–September 2013)	• Mobilization of existing knowledge by discussing with the ABC project management about other organizations or industries or sectors that have knowledge about automation, which could be of interest • Selection of presenters for the K-workshop and discussing with them about the KCP process and their role in it • Planning the K-workshop • K-workshop half-day September 2 • Reflections on the K-workshop and how to set up the C-workshop	How to choose interesting and relevant presentations without giving any of the participants a pole position because the presentation is in line with their expertise? How to ensure that the presented knowledge is "pushing" the participants to expand their way of reasoning?

(continued)

Table 3. (continued)

Steps in action learning research project	Sources of data collection	Phase of KCP process	Main activity	Issues and challenges
		• Concept phase (October–November 2013)	• The research team is formulating conceptual propositions based on the K-workshop as well as the discussions with ABC project management • Selecting 8 concepts out of 10 • Creating mood boards, one for each concept • Planning the C-workshop including group constellations and assigning concepts to the groups • C-workshop half-day November 13 • The researchers act as facilitators when groups work on creating ideas from their concepts. Twenty-two ideas were developed at the C-workshop • Reflections on the C-workshop and how to set up the P-workshop	How to frame crazy, provoking, and paradoxical concepts that still seem relevant for the participants? How to keep mind open and explorative and not go too quickly into solution mindedness? How to support and encourage confrontation, debate and knowledge sharing? From individual perspectives to joint sensemaking
		• Proposal phase (December 2013–January 2014)	• The research team is summarizing the ideas from the posters presented at the C-workshop • A process for the P-workshop is created, which includes a vernissage with the ideas and voting what ideas to jointly explore • P-workshop whole day December 2 • The participants select four ideas to be explored jointly in the collaboration • The collective sensemaking and commitment to define joint projects around the ideas constitutes a collaborative arena for the future work	How can commitment be created and retained? Trust and openness? How to include and convince other members in the participating organizations?
Evaluating process and action	• Evaluation survey from workshop participants (2013) • Field notes and documentation from workshops (2013) • Conversation with ABC Management team (2014)	• (August 2013–May 2014)	• Reflections on and dialoguing around the KCP process and the future	How can we go on together after the KCP process? The role of ABC project management?

Note. KCP = knowledge–concept–proposal.

4.3

three individuals from the research institute constituting the ABC network management. It appeared that these individuals were highly concerned that the work in the network would suffer from, or even fail due to too little trust among the participants and too much politics, which would inhibit their learning from each other. In this section, we provide illustrative quotes from the conversations as well as notes from the observations to depict the challenges the members in the ABC network experienced, the collaborative action and learning activities, and the after-action reflection.

Collaborative Challenges and Risk for Collaborative Inertia

When setting up the ABC network, the management team faced the fact that even if the governmental agency providing the research funds required that certain organizations participated in the network, some of the partners did not even like to collaborate. One of the managers of the ABC network initially said that

> they [the industrial partners] don't like to collaborate, they don't have the habit of collaborating, they don't have that tradition, even when it comes to this area. I still think in their own minds they think that they can do this by themselves.

He continued to say that one of the biggest challenges the network faced was to find common ground and directions to move forward jointly:

> In a sense, the difficulty is going from the politics and shaking hands in those big conventions to actual hands-on projects. And that is where I think this is going to hurt, when we say "Can you collaborate on this?" and they will say, "Oh, but that's secret," or "We are not interested in that area, we have another area that we are interested in," and so on. So I think the challenge here is to extract the concrete examples of where we can collaborate, where we all agree.

Based on these first interviews, authors concluded that there was a concern that the participants would be unwilling to share information, unwilling to compromise, and locked into fixed positions/mind-sets, a diagnosis that the ABC network management team validated. The researchers then proposed KCP method as the process to be used to support collaborative action and learning for starting up the ABC network, and several face-to-face meetings and phone calls and e-mails were needed to dialogue around the KCP method. The ABC management claimed that the collaboration between some of the partners had historically suffered a severe blow, which made them worried that the participants would not be open-minded and share knowledge in the discussion, and therefore, they urged that the KCP process would facilitate openness and constructive dialoguing.

Action Learning: Inviting to Shared Commitment to Action and Learning

When adapting the KCP method to be a part of creating the ABC network by inviting the members to a collective space of reflection, learning, and implementation the researchers and the network management concluded that the initial steps were very important in order to get all the actors involved on board. This implied inviting participants to be peers rather than experts as well as identifying and framing a mode transcending organizational politics. When taking action, this meant that beyond the careful selection of the persons who were to be involved, any past conflicts as well as previous successful collaborations between the participants were thoroughly discussed. The invitation to the workshops was deliberately phrased to mitigate the power struggles, aiming to avoid old battles resurfacing based on conflicting positions. The intention was to set the scene for a collaborative focus emphasizing that no single actor could do this work on their own since there was too much uncertainty, but rather that they were dependent on each other and needed to learn from each other to safeguard the future of the industry in Sweden.

Action Learning: A Questioning and Reflective Process Supporting Learning

Following the KCP process, the K-workshop hosted five experts from adjacent fields (aviation and maritime) brought in to discuss automation from their point of view. Starting out by exploring areas where no one in the network could claim to be an expert was further strengthening the message that within the field of automation "we are all peers and we all gain from learning from each other." The five presentations in the K-workshop triggered a lot of questions, discussions, and reflections among the participants. The researchers noted that the participants were very active in asking questions and sharing their reflections. Little of the feared political play, resistance, and silence could be observed. Also, the ABC network management team seemed very positive about the collaborative atmosphere that emerged during the K-workshop.

The next step according to the KCP process was the C-phase. Before the C-workshop, the researchers and the ABC network management team had prepared eight provocative concepts (e.g., "Driving an un-manned vehicle" about autonomous driving) that were worked on in four groups of four-to-six participants at the C-workshop. The workshop lasted half a day and the groups worked on each concept, made sense of it, discussed it, and came up with possible elaborations/extensions of the concept. The groups needed to create an elevator pitch describing their idea(s), including why the idea was relevant, what stakeholders needed to be involved in the further development of the idea, if there were any existing projects with links to this idea and what knowledge areas were needed to be explored to investigate the idea further.

During the C-workshop it could be observed that some of the participants had a hard time feeling comfortable in discussing hypothetical and speculative ideas not deriving from or being clearly based in the technical knowledge available. Some participants continuously brought up ideas in line with what they already were doing and even articulated irritation that the available knowledge was ignored. The researchers also facilitating the workshop had to remind the participants that they were not supposed to come up with clearly defined problems with solutions strongly attached to their own organizational or personal interests. In conversations during the breaks, the researchers and the ABC network managers discussed that they perceived a risk that if they could not keep the participants in the conceptual and ambiguous state, the conversations among the participants would move into a less trustful and more political mode.

Almost a month after the C-workshop, the P-workshop was carried out. The P-workshop was about reaching an agreement on what aspects related to the development of automated vehicles the ABC network should create around knowledge collectively. This implied an identification of areas for collaboration as well as confirmation of the joint commitment for this work. To secure the commitment of the participants and to build on what they had created during previous workshops, a voting procedure was organized when the 22 ideas resulting from the C-workshop needed to be reduced to 4. It could be observed that when discussing the 22 ideas in smaller groups before the voting, the participants were open about why they thought their organization would not want to collaborate on some ideas, for example, work in progress in some areas that some organizations did not want to reveal and, therefore, chose to stay outside a potential collaboration. In the end, it seemed easy for them to choose among the ideas and the participants seemed satisfied with the four areas chosen.

After-Action Reflection

After the three workshops and as the last part in the action learning research process, we conducted an after-action reflection focusing on the opinions of the participants about the process they had just been through, the experience of the ABC management team as well as the output of the process. The data from an evaluation survey showed that a large majority of the participants claimed that they found the workshop format helpful and that they felt satisfied with the outcomes. The ideas that came out of the peer conversations and collective action showed a significant variety, which the ABC management team in the final conversation claimed was unlikely to have happened if they had not applied such a structured method to explore new paths and support learning.

During the action learning research process, it became clear through our observations that embracing ambiguity and uncertainty implied a challenging paradigm shift for the ABC management team. Even though there were three senior researchers facilitating the process, the learning oriented way of working and the KCP method conflicted with the network managers' traditional approach to management, in which they would focus on planning and controlling the interactions between the participants to accomplish knowledge exchange rather than inviting participants to learn and co-create. As stated by one of the managers:

> The first session was like "WOW," very different. [. . .] But in the end, I think the process was good. I actually think it worked well, and to be honest I didn't think so in the beginning. I wasn't sceptical, but rather worried that we wouldn't make our deliverables.

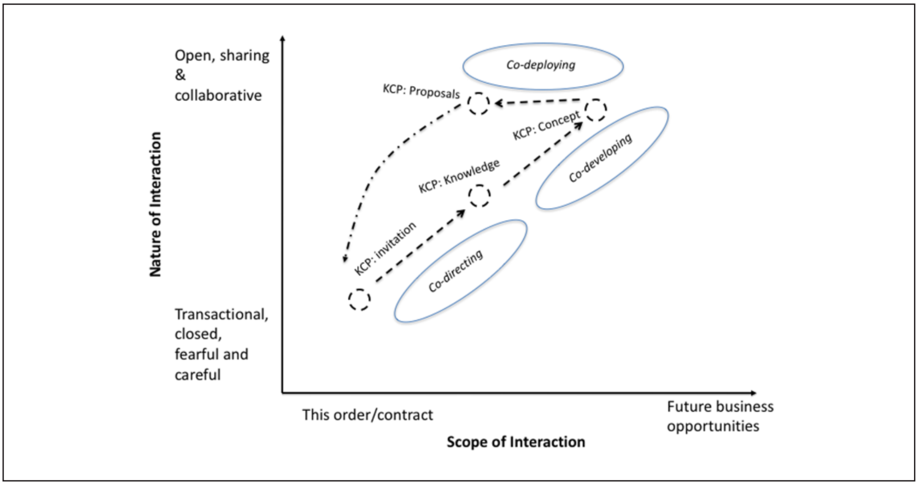

Figure 2. Development of interactions during the action learning process.

Since the action learning research process was finalized, the ABC network has continued to work with three of the four ideas that was generated to form the foundation for future collaborative projects and funding applications related to the development of automated vehicles. Hence, it could be argued that the action learning process appears to have mitigated the challenge of power struggles and distrust and supported the sense of trust among the participants and an idea of how to jointly go on.

From a Strategic Network to a Transformational Network

Indeed, when reflecting on our findings, we specifically note that the nature and scope of the interaction between the participants in the network changed during the action learning research process. These observations together with the steps in the action learning process can be made sense of by using the framework of Coghlan and Coughlan (2015) to elaborate a model that explicates how such a transformation was supported (see Figure 2).

The ABC network managers at least initially described the participants as reluctant to collaborate, as they were not used to collaborative settings and would rather conduct projects by themselves. Based on this we argue that the nature of the interactions in the network were more politically oriented, resembling that of transactional, closed, fearful, and careful. There was a risk when launching the ABC network that the participants would not trust each other, not share knowledge, or engage fully in the work since there had been unsuccessful previous attempts to get the same organizations and individuals to agree upon joint projects within the area of automated vehicles. The participating organizations could have been satisfied just keeping up the appearance of a collaboration, keeping an eye on each other, and advocating their own ideas and technology to be used without being interested in exploring jointly the ideas of others or completely new ones. Using action learning, including codirecting and codeveloping, supported dialoguing and inquiring into the area of joint interest which increased the level of trust and sense of commitment. Discussing the concrete areas where participants could agree to collaborate and jointly exploring new potential ideas regarding the future of the network, that is, co-deploying, further strengthened the trust, and thus, supported the transformation toward interacting in a more open, sharing, and collaborative way. In co-deploying, the participants deepened their understanding for the interest and priorities of the other partners in the ABC network and sealed the commitment for continuing collaboration. As this was the final phase of the KCP method, participants started to consider the implications of the process they had just been through for their organization. When an action learning process including questioning and reflecting comes to an end, there is always the risk of regressing to more transactional, closed, and fearful interactions, as the everyday organizational life with demands on deliverables and short-term results start to come to mind.

Discussion: Supporting Learning in an Interorganizational Network Setting Is to Support Collaboration

Shifting from strategic to transformational interaction appears to be difficult to achieve in practice in interorganizational network settings aiming for collaborative innovation. This article has set out to explore learning as a means of supporting collective knowledge creation by asking: *How can a learning approach support collective knowledge creation in an interorganizational network setting aiming for collaborative innovation?*

Framing Learning in Interorganizational Networks as a Circular Model

Our findings suggest that a learning approach, as developed and applied in the ABC network, mitigated some of the challenges associated with collective knowledge creation and collaboration. Drawing on theories on network action learning (Coghlan & Coughlan, 2015; Coughlan & Coghlan, 2011) and from the experiences of the ABC network, we outline a circular model for learning in interorganizational networks (see Figure 3). Our study shows that network was able to establish a collaborative platform for joint work. The developed model promotes learning as a collective of organizations as opposed to learning as an individual organization, and the former has been described in previous research as important, for for example, networks to be able to make the shift from being transactional to transformational (Coghlan & Coughlan, 2015).

The inner circle in the model illustrates the four phases of the applied method: inviting, knowledge mining, conceptualizing, and proposing. These phases form a collective knowledge creation cycle, and we relate them to the action learning cycle

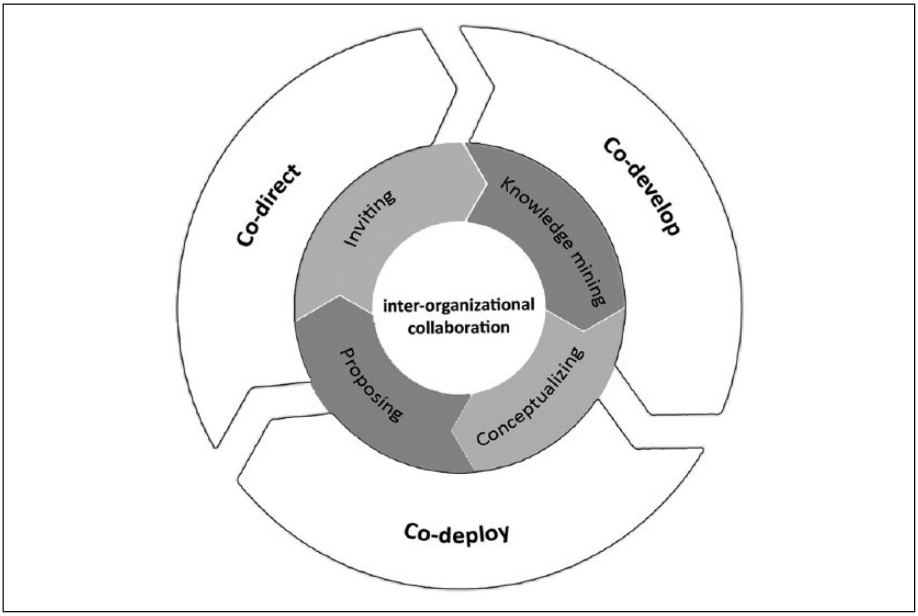

Figure 3. A model for learning in interorganizational networks.

including co-directing, co-developing, and co-deploying, as proposed by Coughlan and Coghlan (2011), to highlight how action learning in interorganizational settings supports collective knowledge creation. The action learning process engaged the participants in peer conversations that were based on the shared commitments to action and to learning, and this supported the willingness to engage in collective knowledge mining and conceptualizing. These two processes contributed to the establishing of a transformational network, a kind of platform for future collaborative innovation.

Transitioning From Strategic to Transformational Network

The transition from strategic to transformational learning-oriented, open interaction was facilitated and supported by several features of the developed model, as illustrated in Figure 4.

First and foremost, participants were positioned as peers rather than experts by means of how the participants were invited, addressed, and related to throughout the process. This appears to be valuable especially as some of the participants had previous experience of failed collaboration with each other. Positions are crucial in collaboration since different positions come with different rights and duties (Harré & Langenhove, 1999), which guide people in how they can act. The peer position allows people to not know, to inquire, to co-create, and to have opinions that may not be fully developed. This is different from the position that most of the participants usually have

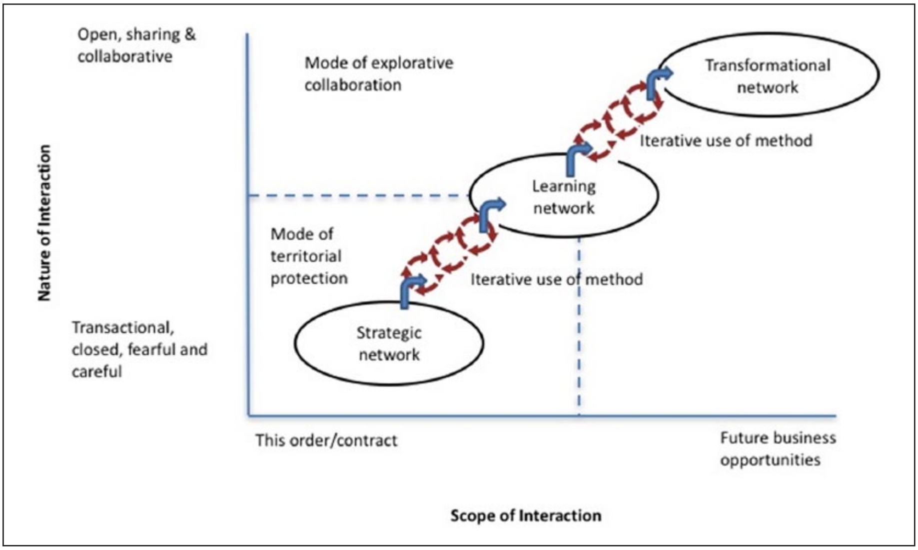

Figure 4. From strategic to transformational interaction in networks.

in normal settings, as the expert position entails to provide solutions, give answers, and make claims without being questioned. In an interorganizational network, a peer position enables change in the nature of the interaction, from a transactional, closed, fearful, and careful, to a more open, sharing, and collaborative. As such, the model depicts how a learning approach invites participants to go beyond their own expertise furthering the notion that no single organization could achieve the results on their own.

The model also reflects the need to invite participants to explore new possibilities together rather than exploit old certainties (March, 1991). In interorganizational networks where there is a high level of politics and low level of trust it might be tempting or even easier for some participants to choose exploitation, that is, to consume the fruits of current capabilities, instead of going for the more risky and complex path of learning. Our conclusion is that managers of interorganizational networks can enable and support co-directing, co-developing, and co-deploying activities to guide participants to knowledge creation and exploration.

Furthermore, the model outlines a process that enables psychological contracting (Argyris, 1960; Rousseau, 1989) as it provides a platform for the participants as well as the management to dialogue around expectations and concerns (cf. Fayard & Metiu, 2014), thus, improving the level of trust and fostering "loyalty" and commitment to the network and its members (cf. Huxham & Beech, 2003; Newell & Swan, 2000). However, as concluded by, for example, Thorgren and Wincent (2011), too much trust between collaborative partners might also reinforce rigidities and create complacency.

Introducing action learning requires much from the management of the interorganizational network collaboration and can imply transforming from a planning and control mind-set to a reflecting and inquiring one. We know from previous research that to become successful, shared innovation processes need to be managed (Bergman et al., 2009), but our conclusion is that it needs to be managed in a way that supports collective learning. We also argue that the managers themselves might need help to be able to support the interaction in a way that enables cocreating solutions and experiences (Keys & Malnight, 2012; Schroll & Mild, 2011).

Many scholars have argued that knowledge creation is required for innovation (Lynn, Mazzuca, Morone, & Paulson, 1998; Madhavan & Grover, 1998; Wallin & von Krogh, 2010), implying that the mere facilitation of knowledge transfer (of existing knowledge) is not enough if innovation is the goal of the collaboration (see, e.g., Faems, Janssens, Madhok, & Van Looy, 2008). The proposed model forms a valuable contribution as it shows that action learning can alter the nature of the interactions as it pushes the interorganizational network out of a space of territorial protection and moves it in the direction of a space for explorative collaboration. Thus, action learning appears to be critical for enabling networks to develop from being strategic (where the focus is on the economics of achieving greater efficiencies) to becoming learning and transformational (where networks learn as a system and adopt the transformation of its participating firms (Docherty et al., 2003).

Conclusions and Managerial Implications

This article has shown the complexities and dynamic reality of implementing action learning to support collaboration in a collective knowledge creation initiative. We have described what emerged as a model for learning in interorganizational network settings aiming for collaborative innovation, at the actual interface of engagement. Our model depicts the shift from a strategic to a transformational network, as the action learning process changed the nature of the interactions and pushed the interorganizational network from a space of territorial protection into a space for collaborative exploration. Our findings confirm previous research on the value of a learning approach to develop collaborative capabilities at the interface of interorganizational network settings (Coghlan & Coughlan, 2015) and to support the transition from a strategic to a transformational network, as well as the need for a structured process to succeed with collective knowledge creation.

Contributions

Based on our empirical exploration of and reflection on this case on action learning we offer three contributions: to theory, to practice, and to methodology.

Contribution to Theory. The question underpinning this article focuses on the ways action learning can support collective knowledge creation in interorganizational network settings. The model proposed gives insights into how a network can shift from being strategic to being transformational by engaging in action learning, which helps change the nature of the interactions in the network. As such, we enriched existing knowledge of collaborative capabilities at the interface of networks (Coghlan &

Coughlan, 2015), by theorizing around the concrete practices that support co-direction, co-development, and co-deployment.

Contribution to Practice. Action learning involves explicit processes of learning-in-action. There is no one best way for organizations to collaborate and move from being a strategic to a transformational network. It involves creating the space for conversation among peers that is grounded in a commitment to action and to learning and is enacted through a questioning and reflective process based on emergent experiential data. Our study shows that through the collaborative engagement with the real-life issues of the firms and the network, participants can come to learn about their own organizations and the network. Senior managers and those who represent their organizations at network meetings and initiatives can draw on the action learning philosophy and methods to create the collaborative environment and exploit the commitments to action and to learning. As evident in our study, for example, past experiences, preconceived notions and rivalry between parties are important to be aware of as they will undoubtedly influence the actions taken, but as our findings indicate, they can also be mitigated and resolved through the action learning process itself.

Contribution to Methodology. How operational and emergent data are gathered, generated, reflected, and acted on in this study provides a foundation for a robust research methodology and methods that are rigorous, reflective, and relevant. Our study shows the relevance and need of action learning research also in complex interorganizational network settings, where such a methodology can have significant impact on the development and learning in the network. What action learning actually entails in this particular setting is in our study made more concrete as we develop a framework guiding the inquiry of how to support collective knowledge creation in an interorganizational network setting and subsequently theorize around the practices that are involved in such learning.

Limitations and Future Research

We acknowledge the limitations of our current research. We offer insights and theorization building on a specific single case study in a specific industry and a specific policy-driven context. Such a single case study approach provides opportunities to develop an in-depth understanding of the practices of collaborative innovation but can limit the generalizability of our findings. Thus, further research is required to corroborate the findings. In particular, comparative studies are required to validate the model proposed in this article. Although the extent of research on interorganizational collaboration and innovation in networks is continuously increasing, the insights from this single case challenges such researchers to turn their contributions into actionable knowledge, not only to add to current theory but also to inform practice. Additional action-oriented studies, focusing on organizations as well as networks, in real time, hold great potential in adding to our understanding of the dynamics of implementation of collective knowledge creation processes.

Authors' Note

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Axe 5 : Nouveaux régimes de création : enjeux culturels et pédagogiques

1) Hatchuel, A. (2019). De la théorie de la conception à l'épistémologie générique : un parcours de recherche avec Anne-Françoise Schmid. In L'aventure épistémologique contemporaine. 2019a

2) Schmid, A-F. (2019). Ouvrages en débat : Science et relativisme. Larry Laudan, Quelques controverses clefs en philosophie des sciences, Editions Matériologiques, 2017, 260 p.Natures Sciences Sociétés, 27(1):101–120, January 2019a

3) Schmid, A-F., and Mambrini-Doudet, M. (2019). L'alliance non-standard de l'épistémologie et de l'esthétique à l'occasion des sciences. Maryse Dennes, John O'Maoilearca et Anne-Françoise Schmid, La philosophie non-standard de François Laruelle, Paris, classiques Garnier, 2019, p. 221-233., 2019.

De la théorie de la conception à l'épistémologie générique : un parcours de recherche avec Anne-Françoise Schmid.

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Une rencontre à Cerisy

Ma première rencontre avec Anne-Françoise Schmid a eu lieu à Cerisy, en 2004, dans le cadre du colloque « Les nouveaux régimes de la conception »[1]. Les contacts qui se nouent à Cerisy - c'est le miracle du lieu- relèvent souvent de l'improbable, ils n'ont sont que plus prometteurs.

Anne-Françoise Schmid venait de la philosophie des sciences et développait ses travaux sur l'éthique du dialogue interdisciplinaire. La théorie de la conception que nous avions développée, n'était encore connue que des spécialistes. Avec Benoit Weil, nous avions souhaité que ce colloque de Cerisy aborde la notion de conception selon deux perspectives complémentaires. D'une part, à travers les différentes traditions professionnelles (Architectes, Ingénieurs, Designers..) où elle s'est incarnée. D'autre part, d'une manière plus unifiée et plus universelle, en retraçant l'histoire intellectuelle de cette notion et celle de ses théorisations les plus récentes qui cherchent précisément à s'affranchir de toute référence à un domaine ou à un métier.

L'intervention d'Anne-Françoise Schmid contribua clairement à nourrir cette seconde perspective. Tout en conservant un point de vue philosophique, elle ne chercha ni à développer une philosophie « en surplomb » de la conception, ni à enfermer cette notion, à toutes forces, dans les discours philosophiques classiques. Elle proposa un chemin plus difficile : celui d'une investigation philosophique qui prendrait d'abord acte des vides du discours philosophique sur la notion de conception et qui accueillerait avec intérêt les questions nouvelles ouvertes par la théorie de la conception. J'ai su plus tard que, venant d'Anne-Françoise Schmid, cette attitude rare, n'avait rien de surprenant. Car l'ouverture de la démarche philosophique et sa mise en tension autour d'objets et de programmes novateurs, sont au cœur même de sa «philosophie ».

L'investigation philosophique proposée avait de nombreuses résonances avec le programme de travail que Benoit Weil et moi-même avions commencé à développer. Il nous fallait encore comprendre les fondements et les implications de la théorie de la conception (dite Théorie C-K

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[1] A. Hatchuel et B.Weil (ss. La dir.), *Les nouveaux régimes de la conception*, Vuibert 2007 et Hermann 2014.

ou Concepts-Connaissances)[2] à laquelle nos efforts de formalisation avaient aboutis. Certes, cette théorie avait montré une réelle efficacité pratique et pédagogique, mais il nous semblait indispensable d'en interroger les présupposés philosophiques ; et surtout, de mettre en évidence les liens, visibles ou invisibles, qui pouvaient exister avec d'autres champs du savoir.

Ecoutons ce que disait Anne-Françoise Schmid, lors de notre première rencontre. La citation mérite d'être reproduite de façon complète, car elle annonçait remarquablement les pistes de travail qui ont nourri, depuis 2004, un compagnonnage continu qui n'a fait que s'amplifier et s'approfondir.

« Le texte qui suit a un caractère programmatique, parce que l'idée de conception dans la philosophie a été très peu développée. Imaginer les effets qu'elle peut y avoir, les transformations qu'elle implique pour sa pratique, identifier le type de résistance que le philosophe offre lorsque l'on parle de la conception, tout cela demande de rassembler des éléments pour le moment théoriquement épars et qui peuvent avoir des objectifs très différents. L'unité même d'un tel projet ne va pas de soi. Cette recherche fait suite aux hypothèses formulées naguère pour comprendre la diversité des objets de l'épistémologie, qui eux aussi relèvent de méthodes et de projets divers, d'histoire, de recherches de critères, d'articulation des disciplines, de tableau philosophique de sciences à des échelles qui peuvent être incompatibles, de vues du monde élaborées par la généralisation de concepts scientifiques, etc. L'attitude adoptée consiste à admettre qu'il existe quelque chose comme la conception et qu'elle n'est pas réductible aux autres objets de l'épistémologie. Elle est possible à condition d'admettre que la recherche de critères de scientificité que l'on a tenté d'établir tout au long du 20ème siècle n'a pas abouti comme telle, parce qu'elle partait d'un concept étroit de la science, lié trop exclusivement à la théorie et à la formulation de lois »[3].

Dans cette démarche Anne-Françoise Schmid a été un soutien constant. Car bien que pleinement philosophe, elle ne croit pas que la philosophie puisse vivre sur elle-même et pour elle-même ; ou qu'elle se réduit à l'éternel commentaire de Platon ou d'Aristote ou enfin qu'elle dispose seule d'un balcon surélevé sur le reste du monde… Anne-Françoise Schmid sait que l'Art de philosopher est toujours en quête d'une invention philosophique, et que celle-ci peut naître là où personne ne l'attend.

Mais en quoi la théorie récente de la conception pouvait-elle justifier un tel programme ? Pour mieux comprendre le parcours de recherche que nous avons partagé, ensuite, avec Anne-Françoise Schmid, il nous faut indiquer quelques éléments de cette théorie,

La conception : logique de l'inconnu et révision épistémologique

Vers 1996, Benoit Weil et moi-même, avions commencé un travail à la fois d'histoire, d'enquête et de formalisation. L'activité de conception était une réalité massive de nos sociétés, mais elle n'avait aucun statut théorique. Son universalité, son caractère énigmatique étaient masqués par des termes peu précis ou par des traditions professionnelles portées à mettre en avant leurs différences bien plus que ce qu'elles ont en commun.

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[2] Cf. Armand Hatchuel, et Benoit Weil, C-K design theory : an advanced Formulation », Research in engineering design 2009, 19: 181-192 ; on pourra aussi se reporter aux nombreuses presentations de la théorie que l'on trouve sur la Toile.

[3] Anne-Françoise Schmid, L'Age de l'épistémologie. Science, Ingénierie, Ethique, Paris, Kimé, 1998.

Cela tient à ce que, tout en ayant une généalogie ancienne, la notion de conception appartient à un phylum de la pensée et de l'action distinct de celui de la philosophique classique. Ce phylum passe par Vitruve et Frontin, par les théoriciens de la rhétorique conceptiste comme Balthazar Gracian[4] ou encore par les théoriciens des machines du 19è siècle…Si l'énigme de la vérité est au cœur de la philosophie classique, la notion de conception se rattache à la question de la pensée et de l'action créatrices de nouveaux mondes, fussent-ils imaginaires. Dans la logique classique, qui sert de référent à la science, l'inconnu réside dans *les anomalies constatées* entre un état du savoir et un état des faits. Dans la logique de la conception, l'inconnu est, au contraire, *une anomalie désirée* [5]: un état du monde qui n'existe pas mais que l'on cherche à faire advenir. Or, cette logique *conceptive* pose de difficiles problèmes à la logique classique. L'histoire des théories de la conception témoigne de nombreuses tentatives intéressantes pour rendre compte des spécificités de la logique conceptive. Chacune de ces étapes étaient aussi dépendantes de l'état général des connaissances et des réflexions philosophiques de son temps.

Il n'est pas possible de présenter ici en détail les prémisses et le formalisme de la théorie contemporaine de la conception (dite Théorie C-K) que nous avons développée d'abord avec Benoit Weil et qui a connu ensuite de nombreux développements par d'autres auteurs. Nous nous limiterons à indiquer quelques questions simples mais difficiles que cette théorie permet de poser et auxquelles elle apporte des réponses rigoureuses sans pour autant être définitives ou complètes.

Le territoire de la conception

En préliminaire, on peut redire qu'un travail ou un raisonnement de conception ne vise pas à répéter le connu. Il se réduirait dans ce cas à un travail de *remémoration*. Il n'y a de conception que *de ce qui n'existe pas encore* et que l'on essaye de penser pour le faire advenir ne serait-ce qu'en imagination ou en représentation par le biais d'une technique d'expression (discours, dessin, son, …).

Cette première approche suffit à soulever des questions difficiles. De quelle logique relève un tel raisonnement? Y-a-t-il des logiques qui explicitent la genèse volontaire d'un objet initialement inconnu ? Le raisonnement de conception est d'autant plus surprenant qu'il ne part donc pas d'une vérité, ni même d'un ensemble de vérités cohérentes, bien au contraire ! Son point de départ, on l'a dit, est une anomalie désirée, un inconnu désirable[6], contrairement à la démarche classique de l'observation scientifique qui s'intéresse aux anomalies constatées. Le raisonnement de conception ne cherche pas à réduire *per se* les défaillances de la connaissance. Il part de ce qui nous manque, de ce dont nous rêvons, de ce que nous désirons voir se réaliser.

Il ne saurait donc se réduire à une démarche classique d'analyse et de synthèse. Car, face à l'inconnu désirable, à ce qui n'existe pas, l'analyse n'a pas de prise. Pour lui en fournir, il faut au préalable, *générer* des réalités provisoires que l'on analysera ensuite pour savoir si elles correspondent ou non à nos désirs. De même, est-il erroné de parler de synthèse pour qualifier un raisonnement qui produit de multiples expansions nouvelles ? Le travail d'un concepteur

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[4] Il s'agit ici de la théorie du « Concepto » développée par Gracian dans son traité : Tratato de l'ingenio y de la agudeza » circa 1648.

[5] Ces notions sont développées dans : A. Hatchuel et al. « Situating design theory : beyond Models and decision » Proceedings ICED conference Seoul 2013.

[6] Hatchuel et Weil 2009

peut prendre de multiples voies qui seront poursuivies, abandonnées, reprises plus ou moins partiellement, hybridées, recombinées, etc. En outre, son déploiement s'opère toujours en lien avec *un remaniement* des connaissances initiales, avec des surprises, voire des découvertes. Le travail de conception provoque inévitablement l'avènement de nouveaux objets, donc de nouveaux *noms* que l'on ne peut décrire comme une banale synthèse entre les anciens noms ! Il s'agit d'un processus *génératif* qui engage les concepteurs autant que le milieu social qui l'accueille. Il ne s'agit pas non plus d'une logique dialectique qui résout les contradictions en les dépassant.

Il est plus rigoureux d'accepter l'existence d'un autre type de logique, *une logique conceptive,* qui s'appuie sur des inconnus désirables pour penser des associations nouvelles et explorer différemment le monde ou nos propres systèmes de pensée. En outre, contrairement aux autres logiques classiques, une logique conceptive ne se construit pas dans un monde clos dont des axiomes préserveraient l'ordre et la signification, ou dont la liste des grandes contradictions seraient connues. Elle inclut toutes les formes de production de connaissances nouvelles. Elle n'existe que comme pensée active, réflexive, et «expansive». Elle exige un monde ouvert, lui aussi inconnu, mais que l'on puisse explorer.

Ainsi, entre la répétition déterministe du connu et l'acte créatif qui n'aurait aucune mémoire et aucune conscience de lui-même, s'ouvre l'immense *territoire* de la conception : un territoire particulièrement luxuriant qui n'avait pas fait l'objet d'une investigation formelle et unifiée.

De surcroît, nous avons pu montrer que le territoire de la conception s'étend à la science-elle-même. Car, la science aussi recherche ce qu'elle désire et ne connaît pas : par exemple, des théories unificatrices ou des outils de modélisation : elle conçoit de ce fait ce qu'elle appelle « connaissance scientifique » autant qu'elle en découvre les contenus. Elle relève inévitablement d'un processus expansif et génératif, dont elle interdit seulement qu'il soit le seul fait d'un observateur isolé[7].

Enfin, la consolidation de la notion de conception ne laisse pas indemne nos représentations de l'action politique et notamment le primat accordé au paradigme de la décision. On sait, qu'au cours du vingtième siècle, la théorie de la décision et du choix rationnel ont dominé la représentation de l'agir moderne. Or, une théorie de la décision ne pense que la manière dont *le choix* s'exerce entre plusieurs alternatives fixées. Elle ne dit rien *de la génération des alternatives*. De façon plus générale, la science sociale elle-même a le plus grand mal à penser la puissance générative d'une société. Notamment, parce qu'elle s'est trop exclusivement construite sur la question des décisions ou celle des mécanismes de pouvoir, ces deux visions ayant en commun de ne pas penser le travail de conception.

Ces quelques éléments éclairent le programme de travail esquissé par Anne-Françoise Schmid :

- la notion de conception et sa théorisation occupent une place laissée vide par la tradition philosophique,
- la notion de conception porte aussi une révision épistémologique, il faut penser la connaissance dans un monde où le rapport entre observateur et observé est génératif. La science ne fait pas qu'étudier des objets déjà là, elle génère ses objets autant qu'elle les observe.

[7] Ibid Hatchuel et al. (2013)

Comme théoriciens de la conception, il nous a semblé qu'un tel programme était inséparable de nos propres travaux et qu'il serait infructueux de séparer la recherche en conception des investigations philosophiques qui lui seraient congruentes. Ce constat nous semblait aussi inviter à des changements institutionnels. Nous avons vite convenu avec Anne-Françoise Schmid que notre propre laboratoire à MinesParistech serait le mieux placé pour l'accueillir et réaliser en commun ce programme de recherche. C'est ce que nous avons pu réaliser dès 2009 quand par accord entre l'INSA et MinesParistech, Anne-Françoise Schmid a été mise à la disposition de notre équipe au sein de la Chaire Théorie et méthodes de la conception innovante.

Depuis, notre compagnonnage avec Anne-Françoise Schmid n'a cessé de se développer et je voudrais évoquer quelques-uns des approfondissements que nous avons menés ensemble durant toutes ces années.

Des correspondances entre démarche scientifique et processus de conception :

Anne-Françoise Schmid est attachée à une philosophie qui pense « sur le terrain ». Et c'est dans l'étude de la production des sciences qu'elle a trouvé son terrain privilégié, car elle peut y analyser les transformations comme des marqueurs épistémologiques.

Pour Anne-Françoise Schmid, l'épistémologie n'est pas transcendante à la science. Elle se construit plutôt de façon immanente à cette dernière, et révèle les opérations et les tensions qui constituent le travail du chercheur. Encore faut-il que le travail ne soit pas totalement discipliné. Car dans ce cas, le travail du chercheur reproduit l'épistémologie préconstruite et constitutive de ses objets et de ses analyses. Anne Françoise s'intéresse aux situations de la recherche où les objets et les disciplines ne suffisent plus. Dans ce cas, le travail de la recherche et celui de l'élaboration épistémologique se superposent : pour progresser, il faut réviser les objets et les cadres disciplinaires.

Dans de tels contextes, la réflexion d'Anne-Françoise Schmid s'articule naturellement aux théorisations de la conception. Car la recherche scientifique y est indissociable d'une démarche de conception de nouveaux objets et de nouveaux domaines. Et de même qu'un raisonnement de conception s'ancre nécessairement dans un inconnu désirable, de même cette recherche aux frontières des disciplines naît-elle de projets transgressant les définitions du savoir institué. Ainsi Anne-Françoise Schmid a-t-elle élaboré des expériences d'épistémologie interdisciplinaire dans lesquelles elle propose aux scientifiques de collaborer à l'étude d'objets étranges qui ne sont pas commensurables aux objets disciplinés. Ces objets qui forcent à se projeter dans l'inconnu, Anne-Françoise Schmid les nomment *« objets intégrateurs* ».

Pour un théoricien de la conception le terme peut surprendre, car sur le plan cognitif, ces objets n'opèrent pas par intégration, et l'on peut montrer que leur premier impact est déconstructeur, puisqu'ils forcent à une révision de certaines des disciplines en présence. Mais la terminologie d'Anne-Françoise Schmid ne vise pas ici la dimension cognitive de cet impact. Elle veut surtout souligner l'effet de coopération interdisciplinaire que ces objets veulent provoquer.

Il en va de même en conception où la multiplicité des points de vue et des compétences est nécessaire mais *insuffisante*. Car il faut aussi que ceux-ci se transforment et s'interpénètrent pour composer l'objet recherché. On retrouve cette logique, dans la recherche aux frontières qu'étudie Anne-Françoise Schmid et pour laquelle elle souligne la nécessité d'une éthique et d'une épistémologie de l'interdisciplinarité. En effet, une simple combinaison des savoirs existants échouerait immanquablement. Et comme aucune discipline ne peut avancer seule, chacune est tributaire non des acquis de l'autre, mais de ses avancées inattendues.

Un autre parallèle avec la théorie de la conception s'est imposé. L'objet intégrateur est nécessairement formulé à partir de ce que la théorie de la conception appelle un « concept ». Cette notion s'éloigne de la définition idéaliste plus commune qui fait du concept une totalité homogène, cohérente et rigoureusement discernable. En conception, le concept est un *germe inconnu, hétérogène, et indécidable* relativement aux connaissances disponibles. Et ce sont ces propriétés qui portent *le potentiel d'expansion* que devra réaliser le concepteur.

Cependant, ces ruptures cognitives nécessitent des espaces d'accueil appropriés. Il faut favoriser les rencontres et respecter les conditions d'émergence et d'expansion. Anne-Françoise Schmid a beaucoup œuvré pour la naissance de tels lieux. Elle ne pense pas qu'il s'agisse seulement d'espaces de socialisation. Car, ils permettraient la rencontre mais sans favoriser les transformations croisées. Ces lieux doivent, à ses yeux, réaliser ce qu'elle a appelé une *intimité collective,* c'est-à-dire une densité suffisante de relations humaines pour que s'opère un abandon relatif des structures sociales de la science ; donc un entre soi, qui favorise une épistémologie de *l'entre-discipline*.

Pour le théoricien de la conception, cette analyse présente de fortes résonances avec ses propres observations: *l'atelier de conception ne peut se réduire à un laboratoire de recherche si le second est seulement perçu comme un lieu d'élaboration des preuves.* L'atelier de conception doit accueillir l'inconnu, le faire naitre et advenir, souvent sous de multiples visages. J'ai coutume de dire que l'atelier de conception, fonctionne comme un film dont le héros est une créature inconnue et invisible que l'on ne peut connaître que par les traces qu'elle laisse ou par les effets que l'on provoque en la soumettant à des épreuves qui sont autant de démarches de visibilisation. Il exige donc une logique d'organisation, de direction, et de coopération qui lui sont spécifiques. La notion d'intimité collective convient parfaitement à l'atelier de conception. On ajoutera, qu'il faut lui adjoindre une vision particulière de *l'autorité* que notre laboratoire a beaucoup explorée.

Mathématiques et théorie de la conception

Les travaux contemporains en théorie de la conception accordent une grande place à l'effort de formalisation. Aujourd'hui, ce que l'on appelle théorie C-K est un modèle formel du raisonnement de conception. Il a fait l'objet de mathématisations différentes selon qu'on l'aborde comme une logique pure ou qu'on introduit des structures d'objets spécifiées (théorie des ensembles, théorie des matroids, …) dans la représentation de l'espace des connaissances. A ce jour, ce modèle a démontré une grande cohérence et a su rendre compte de toutes les spécificités du raisonnement de conception.

Cet aspect de la théorie de la conception contemporaine pouvait être mal compris notamment par des chercheurs en sciences humaines et sociales, qui craignent les effets réducteurs ou la fausse rigueur que l'on a pu observer par une quantification abusive dans certaines disciplines, et notamment en économie. Nous partagions ces craintes et notre recours aux mathématiques vise en tout premier lieu *un gain en compréhension*. Cette démarche exige cependant une grande familiarité avec la formation des objets mathématiques, avec leur capacité à éclairer des relations structurelles ou à explorer des formes et des logiques éloignées de l'intuition commune. Or, sans cette préparation, les mathématiques sont souvent réduites au calcul, et la genèse des notions mathématiques est ignorée.

Il est donc indéniable que notre compagnonnage avec Anne-Françoise Schmid n'aurait pas été aussi complet, si elle n'avait été, comme philosophe des mathématiques, déjà particulièrement préparée à éviter cette idée reçue.[8]

Or, la théorie de la conception a connu un point d'inflexion majeur avec la découverte du Forcing de Paul Cohen à la fois comme modèle d'une logique générative mais aussi pour la puissance subversive de ses résultats. Cette découverte s'accompagne d'un second constat crucial pour notre recherche : l'existence d'une correspondance structurelle étroite, quasiment terme à terme, entre le Forcing et le modèle C-K de la conception. Cette correspondance avait de nombreuses conséquences. La plus importante étant certainement que le modèle C-K pouvait s'interpréter comme un modèle de Forcing général *étendu* à un monde d'objets qui n'obéissent pas nécessairement à la théorie des ensembles[9].

Anne-Françoise Schmid a immédiatement perçu l'intérêt et la profondeur de ces résultats qu'elle a contribué à faire connaître dans sa propre communauté philosophique. Nourrie par ses travaux sur l'épistémologie des modèles, Anne-Françoise Schmid a pu saisir tous les enjeux du Forcing comme modèle d'épreuve pour la théorie de la conception. Il ne s'agit pas d'un réel qui validerait la vérité de la théorie. Mais d'un modèle de référence auquel on pouvait confronter notre propre modélisation. En outre, la puissance, la fécondité et la précision du Forcing sont telles qu'une théorie de la conception qui ne retrouverait pas le Forcing comme régime particulier saurait qu'elle manque singulièrement de généralité. Enfin, inversement, l'étude du Forcing nous a mis sur la voie d'une série de propriétés de la théorie C-K que nous avions peu perçues.

Vers une épistémologie générique

Je voudrais enfin évoquer un projet commun à la fois, le plus ancien et le plus récent. Le plus ancien parce que l'idée d'une « épistémologie conceptive » ou « générique » est probablement née dès notre première rencontre. Le plus récent, parce que nous venons tout juste de publier ensemble, un texte qui tente de préciser les principes d'une telle épistémologie[10].

On le sait, Anne-Françoise Schmid pense que la question majeure de l'épistémologie n'est plus seulement la question de la vérité mais celle de la formation des disciplines. En effet, les disciplines déterminent les objets et les corpus à partir desquels la question de la vérité est posée, dans un second temps. La question épistémologique devrait donc se déplacer des conditions de la vérification, à la question de la genèse des objets scientifiques. C'est là un déplacement qui ne peut plus être pensé dans les termes Kuhniens qui distinguent nettement entre science normale et révolution paradigmatique. Car la question des objets et des disciplines est devenu commune et fréquente du fait même du foisonnement des espaces de recherche. Que l'on pense par exemple aux tensions au sein des sciences sociales ou à la difficile construction

[8] En outre, ses travaux ont fait d'elle une spécialiste de Poincaré, dont on sait qu'il a montré une rare capacité à développer une réflexion épistémologique immanente à ses propres inventions mathématiques

[9] Pour une introduction au Forcing cf. Chapitre « Mathématiques et conception » dans ibid. A. Hatchuel et B. Weil 2014 ; pour la correspondance entre théorie C-K et Forcing cf. : A. Hatchuel et al. , Towards and ontology of design : lessons from C-K theory and Forcing », Research in engineering design 24 (2) 147-163.

[10] A.F Schmid, A. Hatchuel, on generic epistemology, Angelaki Journal of theoretical humanities 2014 19(2), 131-144.

des sciences cognitives. Mais il en va aussi de la biologie, ou des matériaux : la science contemporaine fait en permanence entendre *des craquements* car les disciplines sont toujours là, il en naît d'ailleurs de nouvelles, mais elles sont souvent les gardiennes de territoires qui n'ont plus véritablement de substance ni de pérennité.

Dans ce nouveau contexte de la science, le travail épistémologie ne peut plus s'intéresser aux seules structures du vrai**.** Il ne peut simplement rendre compte de révolutions scientifiques au sein de la même discipline. Et comme dans de nombreux pans de la recherche, la structure disciplinaire forme la référence paradigmatique essentielle, il faut aussi analyser la genèse et l'hybridation disciplinaires. L'épistémologie doit alors devenir « générique », c'est-à-dire faire de la compréhension de cette nouvelle genèse des objets scientifiques, le cœur de son étude.

Une telle épistémologie pourra accompagner, cette mise en danger continu des objets de la recherche, parce qu'elle est d'abord épreuve, sinon souffrance, pour les chercheurs eux-mêmes. Parce qu'elle est aussi une épreuve pour la science comme institution, qui n'a pas encore réussi à trouver une alternative aux disciplines pour se construire socialement.

La théorie de la conception partage ce constat et peut servir de modèle au processus de genèse des objets scientifiques. D'abord en montrant que les objets scientifiques (ou les corpus associés) ne sont pas des « déductions du réel ». La science n'est pas un miroir du vrai. La science est un régime particulier de conception des connaissances qui répond à de nombreux attributs « désirés » : hérédité, répétabilité, appropriabilité qui influencent la construction des tests de vérité. La théorie de la conception fournit aussi un outillage logique qui permet d'expliquer les opérations et les extensions génériques nécessaires au travail scientifique.

A terme, cette épistémologie générique annonce que les objets (ou les idées) scientifiques ne pourront plus être présentés comme des descriptions mais bien comme des opérateurs conditionnels à la recherche (au désir) d'une généricité particulière. On peut aussi penser que les principes de cette *relativité générique* seront la marque des nouvelles sciences. L'épistémologie générique annonce que tout travail de connaissance ne peut se prévaloir seulement du réel mais doit rendre compte des opérateurs d'expansion générique qu'ils utilisent.

Je ne peux terminer ce témoignage sans me faire le porte-parole de tous les chercheurs de la Chaire. Je n'ai pas besoin d'évoquer ici les qualités humaines et pédagogiques d'Anne-Françoise. Elles sont évidentes pour tous ceux qui la connaissent. Je peux dire en leur nom qu'ils ont particulièrement apprécié la manière dont Anne-Françoise Schmid conçoit et pratique ce qu'elle appelle « accompagnement philosophique de la recherche». Chacun a pu constater qu'elle cherchait à susciter la profondeur de la réflexion autant que l'érudition utile. Qu'elle était complice de toute résistance au lit de Procuste disciplinaire à condition qu'elle soit au service d'une véritable invention conceptuelle. Et qu'elle mettait au service de cet accompagnement une disponibilité et une faculté d'écoute rare. Pour tous, Anne-Françoise Schmid incarne dans sa pratique cette intimité collective qu'elle a su si bien penser.

Ouvrages en débat : Science et relativisme. Larry Laudan, Quelques controverses clefs en philosophie des sciences, Éditions Matériologiques, 2017, 260 p.

Anne-Françoise Schmid

Science et relativisme. Quelques controverses clefs en philosophie des sciences 5.2

Larry Laudan
Éditions Matériologiques, 2017, 260 p.

Larry Laudan est bien connu des philosophes des sciences, en particulier pour ses réflexions sur le progrès et ses problèmes en sciences[22]. Cet ouvrage, publié précédemment en anglais par The University of Chicago Press (1990), ne manque pas d'humour, il est une sorte de fiction : il s'agirait de remettre un rapport au Congrès philosophique américain (p. 44 et p. 254) sur « le statut actuel du relativisme épistémique en matière de connaissance scientifique ». L'idée en est venue à la constatation d'un certain « laisser-faire » (p. 41) en philosophie des sciences lorsque les faits et les résultats empiriques ne sont plus pris au sérieux. Les idées d'incommensurabilité entre les théories (Kuhn) ou celle de la sous-détermination par les faits des théories scientifiques en sont des symptômes importants (Quine).

Pour mettre en place la commission, sont choisis quatre collaborateurs, représentants des positions divergentes en philosophie des sciences : le réalisme, le pragmatisme, le positivisme et enfin le relativisme, représentés par des philosophes dont les noms sont construits à partir de noms de philosophes qui les inspirent : Karl (Karl Popper), Percy (Charles Sanders Peirce), Rudy (Rudolf Carnap), Quincy (Willard Van Orman Quine). Si le rapport n'est pas remis, faute d'accord, restent les enregistrements des journées de confrontation, qui forment le gros de l'ouvrage. Une telle présentation permet une distance à la fois critique et divertissante, qui fait le fond du travail présenté dans ces quadri-logues.

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[22] Laudan L., 1977. *Progress and its problems. Toward a theory of scientific growth*, Berkeley, University of California Press.

Les débats tournent autour de l'interprétation de ce qu'est une théorie. Pascal Engel, dans la préface, propose qu'ils soient organisés autour de la notion de vérité[23]. La différence est qu'à partir de la notion de vérité et de son éventuel affaiblissement (théorie « déflationniste » de la vérité), les thèses du relativisme, qui sont celles que veulent contrer l'auteur et le préfacier, sont plus manifestes. Mais les positions des deux auteurs ne sont pas les mêmes, Pascal Engel s'affiche réaliste, pensant que le pragmatisme est le premier stade pour tomber dans le relativisme, et Larry Laudan pragmatiste.

Donc le quadri-logue tourne autour de la notion de théorie. Cependant, aucune caractérisation formelle en est faite, chaque représentant de posture philosophique détient sa propre définition. Pour le positiviste, elle est un système d'équations et elle construit des tests capables de la confirmer et de la soutenir. « Théories et hypothèses sont des constats sur ce qu'il y a dans le monde. Elles sont vraies ou fausses, et sont descriptives » (p. 171). Pour le réaliste, la théorie est un réseau complexe « de suppositions sur les briques de base du monde et sur leurs interactions » (p. 57), ce que le positiviste voit comme « une inflation ontologique » (p. 59). Le réaliste prétend donc « que la science évolue en se rapprochant de plus en plus d'une caractérisation correcte de la nature » (p. 65). Le pragmatiste interprète la théorie comme un ensemble instrumental pour atteindre certaines fins, il évite les assertions ontologiques du réaliste (p. 67), ce qui explique l'intérêt de Laudan pour les problèmes, parce qu'ils sont définis par leurs objectifs (p. 80 et p. 81). Une théorie, plutôt que confirmée comme chez les positivistes, doit être apte à « résister à des tests empiriques de plus en plus exigeants » (p. 67). Le relativiste soutient une posture subjectiviste et sociologique : « Pour schématiser à l'extrême, ce qui vaut comme test d'une théorie est, selon moi, ce que les scientifiques décident d'autoriser comme test » (p. 82). La théorie est une construction relativement arbitraire, dépendant de l'intention de ceux qui la construisent, et le relativiste ne cherche pas à la caractériser en tant que telle. Les théories sont donc approchées comme systèmes d'équation, comme conceptions ontologiques du monde, comme moyens pour atteindre certaines fins dans la connaissance, comme résultant des intentions de ceux qui se caractérisent eux-mêmes comme « scientifiques ». Tout cela révèle des postures philosophiques, mais ne caractérise pas d'un point de vue un peu formel ce qu'est une théorie. C'est l'une des questions ouvertes de cet ouvrage, que nous reprendrons dans la suite.

Le dialogue se poursuit sur plusieurs jours, en se focalisant sur des thèmes qui sont les articulations du quadri-logue. Le premier « Progrès et accumulation des connaissances » traite d'un rapport des théories au progrès. Une théorie plus récente, supposée plus générale, implique-t-elle les plus anciennes ? Les théories plus anciennes peuvent-elles être comprises comme cas limites d'une théorie plus récente (par exemple la théorie de Newton comme cas limite de celle d'Einstein) ? Le passage à une théorie plus générale entraîne-t-il la perte de certains résultats des théories plus restreintes ? Le progrès scientifique dépend-il d'un cumul des théories ? L'empiriste résout ces questions en tenant compte des faits et des équations, le réaliste par la richesse des explications du monde corrélées à des résultats de plus en plus précis, le pragmatiste découple progrès et accumulation : « Je ne vois aucune raison à ce que les changements dignes d'être appelés un progrès ou une contribution à l'accroissement du savoir soient des transitions préservant des connaissances accumulées » (p. 65). Le relativiste met en relation les théories avec les contextes et les agents (p. 83).

Le deuxième thème traite de « la charge théorique et de la sous-détermination ». Le traducteur, Michel Dufour, explique : « Un problème est sous-déterminé lorsqu'il a plusieurs solutions. Ici, il y a sous-détermination lorsque plusieurs théories peuvent rendre compte d'un fait ou d'un ensemble de faits, d'expériences ou d'observations » (p. 86, note 2). Ce thème importe dans le débat parce qu'il met en jeu des positions considérées comme relativistes, en particulier qu'une théorie n'est pas complètement déterminée par les faits. Elle est considérée comme un affaiblissement du rôle du fait dans les sciences, et donc comme un premier pas vers le relativisme. Les théories « n'ont pas de fondement objectif dans les faits, et servent simplement d'instruments commodes au service d'un certain type d'intérêt épistémique » (p. 125). La question principale est donc le rapport du théorique à l'observation et celle de savoir s'il existe des théories équivalentes. Les empiristes admettent la distinction de Carnap entre « énoncés théoriques » et « énoncés observationnels », que les autres n'acceptent pas parce qu'elle repose sur une conception trop pauvre de la théorie, car elle ne reconnaît pas la part théorique des observations. Les empiristes apparaissent comme tenant une position dépassée de la théorie. Le réaliste a du mal à accepter des théories rivales puisqu'une théorie a une charge ontologique. Les acteurs en arrivent à la nécessité de faire une distinction entre une « équivalence sémantique » et une « équivalence empirique » des théories (p. 124), en distinguant les cas positifs d'une théorie et les cas valant comme tests (p. 125) qui, selon le pragmatiste, ne sont pas nécessairement les mêmes.

Le troisième thème a pour nom : « Holisme ». Il est lié au précédent parce que l'idée que la théorie est sous-déterminée par les faits amène à celle qu'un test réussi ne porte pas sur une hypothèse isolée, mais sur un ensemble d'hypothèses – de même pour une réfutation. Lorsqu'un

[23] Engel P., 1989. *La norme du vrai. Philosophie de la logique*, Paris, Gallimard.

test est négatif, on ne sait quelle hypothèse est à supprimer. Cette position, portée par Quine, a pour conséquence qu'on « ne devrait même pas s'attendre à découvrir un jour une défaillance décisive dans un système global » (p. 131), et le relativiste fait de Kuhn son « compagnon en relativisme ». Le relativisme voit l'holisme comme une théorie de la signification, montrant comment un concept interfère avec un système d'autres concepts de la même théorie. On ne peut vérifier ou réfuter une proposition particulière, mais seulement des ensembles. La fin de ce troisième dialogue montre que ces positions relativistes conduisent à des confusions entre réel et potentiel (p. 146), entre rationnel et possible (p. 147).

Avec le quatrième thème, « Critères de succès », est abordée la question de l'objectivité de la méthode scientifique. On imagine les diverses positions soutenant ou critiquant le rationalisme. Le pragmatiste souligne que le scientifique est parfois d'une « naïveté déconcertante » sur les questions méthodologiques (p. 164). Il est possible de faire de la très bonne science, de montrer de la maîtrise sans maîtriser complètement les règles de la méthode. « Les scientifiques font de façon routinière des inférences inductives et commettent ensuite des sophismes déductifs » (p. 167). Pour le positiviste, les règles de méthode sont normatives, elles ne peuvent être qualifiées de vraies ou de fausses (p. 171). Selon le pragmatiste, quelque chose doit être responsable des réussites scientifiques : « À moins que les règles de la méthode scientifique reflètent quelque chose des "faits", la recherche ne serait pas aussi féconde qu'elle est » (p. 171).

La méthode hypothético-déductive vient sur le tapis, utilisée par empiristes, réalistes, pragmatistes, elle est néanmoins reconnue comme fausse par tous. Or, la plupart des théories formelles du concept de théories décrivent celles-ci en fonction de cette méthode, augmentée du théorème de Jacques Herbrand, qui met en relation les hypothèses d'une théorie avec les implications du type « A ɔ B ». La discussion ne permet donc pas de construire une conception formelle de la théorie. La question ouverte que nous posions précédemment est donc fermée. Cette réticence contre la méthode hypothético-déductive explique pourquoi le thème général de l'ouvrage est la théorie plutôt que la vérité, comme le demandait Pascal Engel. Il est difficile de traiter de la vérité dans la théorie si l'on n'a pas une conception de la déduction dans ses rapports aux valeurs de vérité que peut prendre une loi, dont la forme est justement « A ɔ B ». Tout se passe dans l'ouvrage comme si la théorie se décomposait dans les croyances de chacun des participants. Le pragmatiste souligne en effet : « Il me semble que Karl (le réaliste) a souligné que les règles méthodologiques sont elles-mêmes des théories ou des conjectures – conjectures quant à savoir comment il se fait que des objets tels que nous, vivant dans un mode comme le nôtre, puissent classer et choisir parmi les idées qui sont les leurs » (p. 171).

Le dernier thème est celui de l'incommensurabilité des théories et de la possibilité ou de l'impossibilité de la traduction. C'est un thème tenu par les relativistes, en particulier Thomas Kuhn, celui par lequel le relativiste peut être mis en contradiction avec lui-même en soutenant la thèse que « les résultats ne jouent presque aucun rôle dans la formation des croyances des scientifiques » (p. 240). Il est mis en effet en contradiction avec lui-même, car il admet la pluralité des théories scientifiques comme autant de croyances dépendant des contextes et des agents, et il ne peut admettre une recherche sur les causes empiriques de ces croyances – et pourtant, il a une croyance. On peut dire que l'ensemble et le but ultime de l'ouvrage, qui d'ailleurs expose avec soin la diversité des positions relativistes, consiste à mettre à chaque fois en contradiction le relativiste avec lui-même. Beaucoup des arguments contre le relativiste sont finalement des arguments *ad hominem* sur la condition de croyance de l'idée qu'il n'y a pas de croyance bien fondée.

L'ouvrage donne une idée riche et assez complète des débats autour de la notion de théorie, même si les participants ne trouvent pas d'accord final pour la caractériser. Il y a pourtant deux aspects que j'aimerais discuter : la question de la « science » qui figure dans le titre et enfin le rapport de cette philosophie des sciences avec la pratique des scientifiques.

1/ L'ouvrage a pour titre *Science et relativisme*. Et pourtant, dans le déroulé du texte, il ne s'agit pas de science, mais de théorie. Tout se passe comme si pour les philosophes des sciences concernés, la science se réduisait à la théorie. Or, durant la seconde moitié du XXᵉ siècle, s'est développée une science modélisatrice, qui ne critique et n'exclut pas les théories, mais sans doute les déplace. Elles ne sont plus au centre, mais à l'horizon pour garantir la cohérence des modèles et de la modélisation, et éviter, en particulier, les accidents technologiques. Il faut en effet que les hypothèses sur lesquelles reposent les modèles soient compatibles avec les connaissances fondamentales – c'est ce qu'on appelle dans certains laboratoires de conception « remonter dans les modèles ».

La revue *NSS* a joué un rôle important en France depuis plus de vingt ans pour faire voir cette modification de pratique scientifique et pour mettre en évidence les rapports, jamais évidents, entre interdisciplinarité et modélisation. En même temps, à l'étranger, la question de la modélisation était reprise, non pas dans l'épistémologie, mais dans les *sciences studies*, c'est-à-dire la sociologie des sciences. Il a fallu attendre le début du XXIᵉ siècle pour que les modèles et la modélisation aient vraiment leur place dans l'épistémologie et la philosophie des sciences[24].

La raison de ce retard a été que les modèles ont été essentiellement compris comme interprétation vraie des théories[25] et comme médiateurs entre la théorie et l'expérience[26]. Ces deux postures limitent la validité des modèles, la première en rejetant comme idéologique tout modèle obtenu par observation du réel, la seconde en restreignant l'autonomie relative des modèles, les plaçant toujours dans l'opposition philosophique entre théorie et expérience. La modélisation telle qu'elle est pratiquée maintenant dans les régimes interdisciplinaires de la science suppose l'ouverture de telles oppositions ou complémentarités[27].

2/ L'ouvrage souligne par deux fois la naïveté des scientifiques face à la connaissance effective des méthodes de leur propre science. Bien entendu, il y a une forme de « naïveté » dans la façon dont les scientifiques font confiance au réel, et il me semble que c'est une bonne naïveté. Il y a parfois aussi une naïveté lorsqu'ils prennent leurs propres méthodes comme plus objectives que celles de collègues d'autres disciplines. Cette deuxième naïveté finit par disparaître dans les pratiques interdisciplinaires, qui intègrent aussi bien des sciences exactes, dures, molles, sociales, humaines, ainsi que les épistémologies qui les accompagnent, comme c'est le cas, par exemple, dans les problèmes d'ingénierie et de design.

Mais si les scientifiques considèrent comme très éloignés de leur travail les débats de l'ouvrage, c'est que leur pratique ne se limite pas à la théorie. Si l'on étend aux modèles ce qui y est dit sur les théories, on aura sans doute quelque surprise, parce que chacune des interprétations pourra, avec d'importantes nuances évidemment, en même temps ou alternativement concerner tous les modèles. Ceux-ci peuvent être vus empiriques (ils mettent des fragments de théorie en rapport au réel), réalistes (ils décrivent au plus près la réalité empirique par la mesure et l'observation), pragmatistes (les modèles sont des outils en vue d'un objectif scientifique) ou relativiste (le modèle est multiple, par définition, et peut être vu comme précurseur de nouvelles théories rivales ou d'un nouveau champ d'observation). Ces notions ne vont pas toujours ensemble, mais elles ne sont plus exclusives. Bien entendu, il y a de grandes différences entre les modèles, ils peuvent être descriptifs, prédictifs, heuristiques, servir de résumé ou de « maquette » d'un problème, etc. Mais ces différences sont indépendantes des postures développées dans l'ouvrage.

Cette question n'est pas un détail. Elle traite de la question de savoir comment la philosophie dite des sciences ou de la science concerne effectivement les sciences et les scientifiques. Le langage nous fait croire qu'il y a une philosophie des sciences, comme il y a une philosophie de l'art ou de la technologie. Le « de » suppose que la philosophie est une sorte d'universel. Il y a en effet des philosophies et elles donnent effectivement des critères pour déterminer ce qui peut être compris comme universel ou encore les « normes du vrai » (Pascal Engel). Mais que la philosophie puisse, au nom de cet universel, survoler les sciences ou les arts ou les technologies est maintenant souvent mis en doute, au profit d'une immersion de fragments de philosophies dans des pratiques et des sciences qui ne relèvent pas de la philosophie. Celle-ci n'est évidemment pas une science générique pour les autres, mais elle permet des liens entre des fragments de sciences dans les pratiques interdisciplinaires. Et cela pourrait donner raison à leur manière à toutes les postures. Même l'empiriste pourrait nous montrer comment un fragment de sciences pourrait être, via un fragment philosophique, mis en rapport à l'empirique. Gilles-Gaston Granger avait montré l'importance de l'empirisme dans les sciences contemporaines[28]. Mais il avait dans le même temps souligné la valeur de connaissance de la philosophie[29].

Le réaliste trouve aussi sa place dans l'ouvrage, mais d'une façon plus radicale qu'on aurait pu le supposer. Ce dernier voit le réel dans une relation quasi dialectique avec les théories scientifiques. Dans les régimes interdisciplinaires de la science, cela n'est plus possible sans contradiction. Il suppose, à la façon naïve du scientifique, un réel indépendant à la science et à la philosophie. Le réalisme change alors de sens : tout fragment de science peut être rapporté au réel, même conçu par un pragmatiste ou un relativiste. Il me semble que le réaliste aujourd'hui ne peut plus refuser les

[24] En France, Varenne F., Silberstein M., Dutreuil S., Huneman P. (Eds), 2014. *Modéliser et simuler. Épistémologies et pratiques de la modélisation et de la simulation, tome 2*, Paris, Éditions Matériologiques.

[25] Badiou A., 1969. *Le concept de modèle. Introduction à une épistémologie matérialiste des mathématiques*, Paris, François Maspero. Réédité en 2007 chez Fayard, sans modification de ce qu'il y déclare sur les modèles.

[26] Morgan M.S., Morrison M. (Eds), 1999. *Models as mediators. Perspectives on natural and social sciences*, Cambridge, Cambridge University Press.

[27] Schmid A.-F., Hatchuel A., 2014. On generic epistemology, *Angelaki, Journal of the Theoretical Humanities*, 19, 2, 131-144.

[28] Granger G.-G., 1992. *La Vérification*, Paris, Odile Jacob.

[29] Granger G.-G., 1988. *Pour la connaissance philosophique*, Paris, Odile Jacob.

multiplicités de la science et le pluralisme qui s’ensuit[30], et cela modifie sa définition.

Le pragmatiste interprète les modèles aisément comme des outils permettant de mieux connaître le monde dans lequel nous vivons.

Et le relativiste se fait une joie de la multiplicité des modèles, qui est incontournable, comme l’avait déjà fait remarquer Poincaré[31].

Ainsi, ces postures philosophiques deviennent des sortes de valeurs épistémiques, plus locales, plus flexibles que lorsqu’elles sont comprises à partir de la seule philosophie des sciences, celle-ci contribuant mais ne suffisant plus à déterminer de telles valeurs.

Elles peuvent intervenir aussi à plusieurs échelles, il est possible d’avoir un point de vue pragmatiste sur les philosophies, sans que chaque philosophie soit pragmatiste.

Je fais le rêve que Larry Laudan, pragmatiste, accepterait cette extension des sciences par l’épistémologie des modèles et de la modélisation ainsi que les modifications des postures philosophiques qu’elles impliquent.

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Humanités environnementales. Enquêtes et contre-enquêtes

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CLASSIQUES GARNIER

SCHMID (Anne-Françoise), MAMBRINI-DOUDET (Muriel), « L'alliance non-standard de l'épistémologie et de l'esthétique à l'occasion des sciences », *in* DENNES (Maryse), Ó MAIOLEARCA (John), SCHMID (Anne-Françoise) (dir.), *La Philosophie non-standard de François Laruelle*, p. 221-233

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SCHMID (Anne-Françoise), MAMBRINI-DOUDET (Muriel), « L'alliance non-standard de l'épistémologie et de l'esthétique à l'occasion des sciences »

RÉSUMÉ – L'un des acquis de la philosophie non-standard est de mettre en évidence dans l'organisation de la recherche le rôle de disciplines qui ont un rôle de sous-détermination. Il y a des disciplines qui n'ajoutent rien positivement, mais sont nécessaires pour l'organisation de la recherche et la conception de ses objets. L'objectif de cette contribution est de montrer la nécessité de l'usage sous-déterminant de disciplines et de manifester ainsi de nouvelles alliances non-positivistes entre elles.

MOTS-CLÉS – Science, épistémologie, esthétique, quantique, exclusion

L'ALLIANCE NON-STANDARD DE L'ÉPISTÉMOLOGIE ET DE L'ESTHÉTIQUE À L'OCCASION DES SCIENCES

« … nul n'entrera ici s'il n'accepte l'épreuve d'un formalisme conceptuel… »
Philosophie non-standard, p. 43

« Une science constitue classiquement son domaine d'objets à partir de connaissances acquises et d'une constante nouvelle qui l'ouvre et le ferme sur un réseau renouvelé de relations multiples. L'intérêt d'une constante comme le générique au sens où nous l'entendons est que tout en conservant une fonction scientifique elle est pertinente pour les phénomènes du champ philosophique et rend donc prévisible une modélisation qui ne soit pas une activité externe ajoutée à une science classiquement fermée. »
Philosophie non-standard, p. 207-208.

INTRODUCTION

L'un des acquis de la philosophie non-standard est de mettre en évidence dans l'organisation de la recherche le rôle de disciplines qui ont un rôle de sous-détermination. Il y a des disciplines qui n'ajoutent rien positivement, mais sont nécessaires pour l'organisation de la recherche et la conception de ses objets. L'objectif de cette contribution est de montrer la nécessité de l'usage sous-déterminant de disciplines, de les donner à palper du point de vue de la recherche et de manifester ainsi de nouvelles alliances non-positivistes entre disciplines.

L'épistémologie et l'esthétique ont presque toujours été séparées pour la compréhension des sciences. Mais celles-ci deviennent à ce point interdisciplinaires dans leur pratique que cette séparation n'a plus lieu d'être. Par exemple, les données ne peuvent plus être comprises comme les corrélats d'hypothèses théoriques, comme des faits, et demandent, pour leur interprétation, ensemble esthétique et épistémologie générique, qui n'interviennent pas comme discipline de plus, mais comme sous-détermination de l'organisation de la multiplicité de celles en jeu… Pour cela, il faut une méthode, qui permette, en deçà des disciplines, de construire un espace de traduction générique des propositions disciplinaires. Dans cette démarche générique, les liens entre les sciences et l'humain, Nouvelle Alliance « sans » disciplines positives se manifestent. Ce changement de méthode d'appréhension des sciences sera mis en œuvre à l'occasion de nouveaux objets, où homme, science, technique, éthique semblent intriqués, mais l'alliance entre épistémologie et esthétique permettra de marquer des niveaux, des superpositions et des dynamiques entre les objets et l'homme générique de François Laruelle, et traiter leur intrication par la « conjugaison » des sciences et de la philosophie.

LE SYMPTÔME

Qu'est-ce qui manque autour des objets intégratifs, des modèles, des data pour les comprendre dans le contexte contemporain ? On cherche habituellement à les recouvrir par les disciplines, mais il y manque quelque chose. Une scientifique, Muriel Mambrini-Doudet, va le mettre en évidence sous la forme d'un symptôme : la trace de l'homme dans la conception et l'évaluation. Ce qui manque à la recherche, c'est l'homme qui fonde les « trajectoires » dans les objets intégratifs, les modèles et les data. Et cela on peut le faire voir à travers la fonction de discipline sous-déterminante.

Toute discipline peut jouer le rôle de discipline sous-déterminante. On pourrait lire l'œuvre de Freud en choisissant pour discipline sous déterminante la thermodynamique, ou celle de Michel Foucault en choisissant la géologie, celle de François Laruelle avec la Quantique. La discipline SD est-elle celle qui fournit les métaphores à une œuvre ? Ce n'est pas si simple, c'est plutôt elle qui fait que ces métaphores ne sont pas seulement des métaphores – « il n'y a pas de métaphore » disait Deleuze, ce à quoi la philosophie non-standard répond que l'intrication de la métaphore et de la non-métaphore sont la marque de la DSD. Lorsque celle-ci devient manifeste, la métaphore en tant que telle s'efface.

Mais cela est un après-coup : il y a une œuvre, et l'on cherche à la comprendre autrement que par la linéarité du texte et apporte de nouveaux résultats à la fois sur l'œuvre et sur ce qu'on appelait métaphore. Il s'agit ici, plutôt que d'œuvres déjà données, de voir comment dans la recherche, celle qui n'est pas donnée d'avance, celle en train de se faire, un tel concept a son efficience. C'est pourquoi nous donnons à deux cette conférence, collaboration entre une philosophe, épistémologue parmi les scientifiques, dont le travail a toujours été de comprendre les méthodes scientifiques et les philosophies, sans pratiquer d'exclusion, et une biologiste, qui deux ans, a été la conseillère scientifique du PDG de l'INRA, puis six ans Présidente du plus gros centre de l'INRA.

DISCIPLINE

Nous nous référerons souvent à la notion de discipline. Pourtant, nous ne la reprenons pas telle quelle, car il faut la traiter. La discipline est à la fois rassemblée par des généralités théoriques, des formes d'évidence sur la reconnaissance des bons problèmes dans une conjoncture donnée, les liens entre ces deux fait de la discipline un lieu dynamique où se trouve déjà de l'interdiscipline. Mais la discipline est aussi un mode de défense d'un territoire et une forme d'église scientifique. Les liens entre ces trois aspects du terme « discipline » donnent lieu à tous de sortes de conception fantasmatiques, où les changements d'échelle ne sont pas maîtrisés ou plutôt non reconnus comme tels. Nous ne pouvons réduire cet aspect fantasmatique. Par contre nous pouvons « traiter » les disciplines, en veillant à ce qu'aucune ne domine les autres, que ce soit la philosophie, les mathématiques, ou encore la biologie moléculaire. Il ne s'agit en aucun cas de les supprimer, mais de modifier leurs relations dans une recherche dont les régimes sont de plus en plus explicitement interdisciplinaires.

GÉNÉRIQUE

Cette règle de transformation des disciplines conduit à une épistémologie générique, relativement indépendante des disciplines. Mais ce décollement des disciplines ne suffit pas à caractériser une épistémologie générique. Il y a deux moments du générique, celui, le plus simple, où on « sort » une notion d'une discipline, où l'on décompose une proposition de façon à la rendre compatible avec d'autres disciplines, ainsi que Kant l'a fait pour le concept de grandeur négative. Mais le second moment est celui où l'on s'aperçoit qu'il faut un élément étranger d'une autre nature pour faire la recomposition et en rendre possible la dynamique, que ce soit dans une recherche particulière ou dans l'organisation de la recherche. Le premier moment est partiellement statique, le second essentiellement dynamique.

Par exemple on dit souvent que la création de continents scientifiques suppose la « sortie » de concepts de la philosophie, traitées ensuite autrement, articulés à la mesure à l'expérience. C'est une vision idéologique de l'histoire des sciences, tant que l'on ne voit pas la fonction du générique, indifférent aux disciplines, et qui pourrait aussi bien inaugurer un nouvel usage de la notion en philosophie elle-même. Le générique donne à la fois liberté et rigueur au générique aussi bien à la sortie qu'à l'entrée des disciplines.

DISCIPLINE TRAITÉE ET DISCIPLINE SOUS DÉTERMINANTE (DSD)

Une fois traitée, une discipline n'est jamais pensée en isolation, comme dans l'histoire des sciences classiques, où sont négligées les superpositions de fragments de sciences différents dans l'organisation d'une théorie pensée comme unifiée.

Mais une pluralité numérique de disciplines scientifiques ne permet pas de rendre compte des objets scientifiques contemporains, sinon on suppose l'objet comme donné, comme rassemblant lui-même cette diversité disciplinaire, et sur lequel les perspectives disciplinaires peuvent par conséquent converger. Mais on sait maintenant que les objets sont des X non donnés, on ne peut plus supposer la synthèse en eux. Il faut une organisation partielle des relations entre disciplines, pour permette de construire des extensions permettant de penser l'objet. Dans un cadre non traité, la discipline sous-déterminante est souvent remplacée par une discipline dominante. On en sait la conséquence, les objets sont alors traités comme des produits technologiques de cette discipline, comme les OGM de la biologie moléculaire, ce qui ne permet plus de les évaluer qu'en confondant jugement moral et posture éthique, et divise l'éthique entre le bien et le mal

DEUX HYPOTHÈSES

Nous allons proposer deux hypothèses. Des hypothèses et non des conjectures. La conjecture construit une continuité à partir d'un état supposé des sciences. L'hypothèse au contraire fait une coupe, est transversale, ne construit pas de continuité si ce n'est partielle. C'est à ce niveau de l'hypothèse que nous voulons intervenir, pour exhiber de ce que nous pouvons comprendre des relations entre épistémologie et esthétique dans leurs rapports aux sciences, et construire ce que nous appellerons une Nouvelle Alliance « sans » discipline.

Ces hypothèses supposent que les sciences ne sont pas linéaires, que les diagrammes, comme le dit John O'Maoilearca, les compositions de modèles, comme dit Frank Varenne, les superpositions, comme dit François Laruelle, font partie de la structure même de la science, et ne sont pas seulement les effets d'une complexification de linéarités originales supposées. Peut-être y a-t-il du simple dans la science, mais ce n'est pas sous la forme de linéarité discursive, même si celle-ci fait partie à des degrés divers de la fabrique de la science. Il y a des morceaux de linéarité, mais ils restent partiels. Il y a des superpositions de raisonnements scientifiques, qui eux-mêmes sont des raisonnements scientifiques.

Cette conception modifie profondément l'épistémologie du XX^e^ siècle, construite autour de la complémentarité entre théorie et fait. Il faut ouvrir cette tension, admettre qu'il y a des théories, admettre qu'il y a des faits, mais ne pas restreindre les ingrédients philosophiques à être des intermédiaires entre ce qui avait été utilisé comme les deux pôles de l'activité scientifique. Il y a une épaisseur beaucoup plus grande au raisonnement scientifique, qui suppose des superpositions de fragments de sciences hétérogènes. Dans l'épistémologie classique, l'hétérogénéité est rejetée dans le « réel », la fonction de la science étant, au travers les mathématiques, de construire de l'homogénéité. Mais cette posture supposait une conception fermée autour de la théorie, garantissant une forme d'homogénéité.

Les régimes interdisciplinaires des sciences contemporaines, tout en admettant l'importance des théories, ne peut en rester à cette conception lissée de la science. Celle-ci avait déjà été mise à mal par l'étude des expériences, faisant usage de matériaux relevant de diverses théories, par celle des instruments scientifiques, ainsi que du fonctionnement social des sciences. Mais malgré tout, on admettait que quelque chose du concept unificateur répondait toujours à cette conception homogène de la science. L'hétérogénéité de la science ne signifie pas sa carence d'identité, mais celle-ci doit être conceptuellement retravaillée, de telle sorte que la philosophie ne la survole pas, mais se mette à côté d'elle, en tenant compte des modifications que cette juxtaposition signifie, ce que nous avons appelé le « traitement des disciplines ».

HYPOTHÈSE 1
L'épistémologie serait une DSD

Que fait voir l'épistémologie en tant que sous-déterminante ?

Quelque chose d'une substance scientifique qui déborde les disciplines et une rigueur qui met en jeu une hétérogénéité d'éléments et des modes de compatibilité et d'hyper-compatibilité entre eux. Elle permet de caractériser les flux de connaissances, de distinguer les ingrédients de la science, de permettre de manifester leurs formes de conception.

Par exemple, si l'épistémologie est DSD de la biologie de synthèse, elle ne la verra plus seulement comme ingénierie de la biologie et ses produits comme ceux d'une technologie. Elle est sans doute cela aussi, mais l'épistémologie DSD fera voir qu'elle n'est plus une science expérimentale au sens classique, outillée par les mathématiques et l'informatique, mais que les mathématiques, l'informatique, les biologies deviennent relativement autonomes pour permettre des flux de connaissances dans un sens beaucoup plus libre que dans ce que l'on appelait science expérimentale, avec son unité apparente et sa forme d'homogénéité. Il y a une hétérogénéité qui reforme une forme d'unité partielle, à la fois science pure et technologie, permettant l'articulation des éléments hétérogènes par la conception de modules. L'épistémologie donne ainsi une beaucoup plus grande épaisseur scientifique à ce que l'on appelle biologie de synthèse.

L'épistémologie ne prend pas la place d'un fondement, mais au contraire elle sous-détermine, c'est-à-dire décompose la fondation homogène réduite à la bio-ingénierie, mais fait voir de nouveaux flux de connaissance qui nous donnent de nouvelles indications sur les disciplines émergentes sur fond interdisciplinaire. Il s'agit de chercher ce qu'est la biologie de synthèse en régime épistémologique. Les produits alors sont compris en amont, pas seulement comme techniques, mais comme accompagnant une démarche scientifique.

L'épistémologie permet alors de distinguer les ingrédients entrant dans la démarche, sans les unifier en fonction d'un plan exclusif. Le propre des objets contemporains étant de pouvoir être perçus alternativement ou dans le même temps comme scientifiques, comme techniques, comme sociaux, les uns n'annulant pas les autres. La DSD permet de sauvegarder et de faire voir cette hétérogénéité, qui n'est réductible par aucune discipline, même pas les mathématiques, qui jouent alors un rôle de connaissance à part entière. Il y a des fragments de bio-ingénierie, mais qui ne forment pas un plan d'homogénéité pour toute la biologie de synthèse.

L'épistémologie fonctionnera alors comme un mode de conception des objets X de synthèse. Cette démarche de conception est essentielle pour comprendre la dynamique de création. Si l'on interprète au travers d'une épistémologie classique, on y verra l'intention des chercheurs comme permettant de rassembler l'hétérogénéité des éléments. La DSD décompose cette intention, défait la continuité entre le chercheur et son objet, et ne la voit plus comme « trajectoire » sans objet ni sujet. Néanmoins, l'épistémologie ne voit pas ces trajectoires dans leur singularité, mais comme possibles parmi de multiples trajectoires. Elle ne voit les trajectoires que grâce à l'analogie avec la multiplicité de principe des modèles – il suffit de montrer qu'il y en a un, mais il ne faut pas se fixer sur un particulier, comme l'avait très bien montré Poincaré. Elle sait qu'il y a des trajectoires, mais ne peut si l'on peut dire, ne les traiter que par « paquets ». Ce savoir est celui d'une science d'invention et de conception collective.

C'est une science de concepts qui permet une rigueur par la compatibilité entre les fragments de disciplines et les connaissances fondamentales, et la traduction générique de ces fragments, leur permettant d'être articulés à d'autres fragments.

Si l'épistémologie fonctionne comme DSD, que voit-elle de l'esthétique ? Elle ne la voit que par analogie aux modèles. Elle ne peut saisir les trajectoires individuellement.

HYPOTHÈSE 2
L'esthétique serait une DSD

Sous-déterminante, nous ne comprenons pas l'esthétique comme une sous-discipline de la philosophie. L'esthétique est plus composite que l'épistémologie, qui tend à articuler les sciences par les concepts. L'esthétique est sans concept, plus préoccupée de faire œuvre, d'articuler des fragments de disciplines et de créer des trajectoires, de permettre de les faire voir. Elle fait création de l'œuvre qui l'engage et permet de l'évaluer, elle participe à la fois à la création de l'objet et au rapport de la trajectoire à l'objet. L'esthétique permet de prendre en compte la production des nouveaux objets, en faisant voir d'une part leur formes et séries inchoatives (comme pour les données). Plutôt que substance et rigueur, elle est beauté et exigence, exigence de faire œuvre, elle fait voir des orientations qu'une discipline en isolation ne peut à elle seule décrire.

Lorsqu'un objet est hétérogène, tel qu'il ne peut être compris ni par une discipline, ni par leur recouvrement convergent, il ne peut être suggéré que par fragments inchoatifs, qui donnent une orientation et une dynamique. L'esthétique est donc nécessaire au deuxième moment du générique. C'est ce que manifeste l'esthétique, qui nous propose à la fois les séries inchoatives et des modèles d'art. Cela est essentiel pour tout ingrédient scientifique qui n'est pas le corrélat d'une hypothèse théorique, mais qui peut être interprété par autant de théories que l'on veut. C'est ainsi que l'on a maintenant des offres de fonds de recherche pour exploiter des données, par exemple celles de la NASA, dont une grande partie restent inexploitées, et que bien des disciplines peuvent interpréter à leur manière en partant d'une orientation, de séries qu'elles présentent. Pour cela, il faut un intermédiaire esthétique, si ténu fût-il. L'esthétique est la connaissance de la trajectoire sans concept, qui confine à la perfection, mais qui n'environne pas les flux de connaissances, comme le fait l'épistémologie et ses concepts.

Si l'esthétique est DSD pour la biologie de synthèse, elle fait voir les rapprochements rapides entre modélisation mathématique, science informatique et disciplines biologiques à chaque fois comme de nouvelles trajectoires, et devient compatible avec des modèles d'œuvres d'art, elle propose des synthèses minimales que l'épistémologie défait pour faire voir les flux de connaissances. L'épistémologie générique décompose les ingrédients pour en faire des instances autonomes, l'esthétique indique des trajectoires particulières entre ces fragments.

Qu'est-ce que l'esthétique comme DSD fait voir de l'épistémologie ? Elle ne peut la trouver que comme conception, et non comme théorie de justification. Si l'épistémologie est comprise comme science d'invention collective, elle peut être perçue par l'esthétique. Le concept d'« intimité collective » par lequel nous traitons les nouveaux modes d'échange scientifique dans un espace générique est perçu dans la mesure où il permet des trajectoires libres des logiques disciplinaires.

NOUVELLE ALLIANCE « SANS » DISCIPLINE

Peut-on faire une alliance de l'épistémologie et de l'esthétique pour comprendre les sciences contemporaines ? Une alliance non symétrique, l'une et l'autre n'intervenant pas au même niveau. Il y faut des superpositions, la construction d'intermédiaires formant un lieu, un mi-lieu, – et non plus le passage de contraires – où chaque DSD intervienne comme non pas comme discipline formée et homogène, mais comme fragment, ou comme dimension « sans » discipline. Le « sans » a quelque chose à voir avec la sous-détermination : que reste-t-il de l'esthétique lorsque l'on considère l'épistémologie ? Que reste-t-il de l'épistémologie lorsque l'on considère l'esthétique ? Ces questions engagent une dynamique, une orientation, qui permettent d'étendre des aspects non-vus de la science.

C'est une façon de défaire la « philosophie des sciences ». En effet, comment définir la philosophie de façon classique si ce n'est en la considérant comme l'invariant de multiples surdéterminations. La philosophie se manifeste au travers de la science, de la technologie, de l'éthique, de l'esthétique, de l'épistémologie, de la religion, sans toutefois se réduire à elles. C'est comme cela que l'on a pu faire une philosophie de …, philosophie des sciences, philosophie des religions, de la technologie, de l'art, où la philosophie est dominante. En traitant les disciplines, on peut transformer ces déterminations à la fois extérieures et internes à la philosophie, en sous-détermination, sans suffisance. Tous les ouvrages de François Laruelle sont conçus ainsi, non pas comme surdéterminations, mais comme la fusion de la philosophie avec un X sous ce X qui n'est pas un fondement.

SURDÉTERMINATION ET EXCLUSION

Cela défait les exclusions produites par la surdétermination, parce que la philosophie dans la sous-détermination est pensée comme générique, et non pas comme la guerre d'une philosophie contre une autre. Cela ne veut pas dire une philosophie qui serait le plus petit commun dénominateur des philosophies, ce que l'on n'obtient que de points de vue philosophiques particuliers. Le générique suppose une façon de rapporter le philosophique à l'humain, c'est-à-dire à la décoller de sa suffisance. Il est alors possible de superposer des propositions philosophiques, un peu comme nous avons superposé esthétique et épistémologie « sous » la science. La sous-détermination limite l'exclusion sans interdire l'orientation, ce n'est pas une indifférenciation, mais une façon de voir les sciences à travers des dimensions et des niveaux qui, dans leurs relations, permettent de nouvelles fictions et de nouvelles extensions.

Cette nouvelle alliance n'est pas celle de la nature et de l'homme, qui suppose les règles de la réversibilité philosophique. Elle n'est pas totalisante, elle est multiple, et se fait par « bouts » et « fragments », non pas une fois et définitivement. Cette nouvelle alliance est beaucoup moins super-visante, elle est juste une façon d'expliciter comment des fragments de disciplines peuvent intervenir non pour surdéterminer des objets connus, mais pour étendre un X qui contribue à nous faire voir la science sans exclusion. Ce qui ne signifie pas que la science est n'importe quoi, qu'il suffise de ne pas exclure pour avoir de la science. L'épistémologie comme DSD donne les conditions de compatibilité et d'hyper-compatibilité, que nous avons appelé « critère de Poincaré ». Les ingrédients des sciences ne sont pas indifférents ou ambivalents. La discipline SD en assure le rapport à quelque chose de réel. C'est un intermédiaire qui n'est plus abstrait, mais qui se donne les moyens de penser les symptômes de l'absence de l'homme.

UNE LOGIQUE DE LA NON-RÉVERSIBILITÉ

Prendre une DSD ne donne pas les mêmes extensions que d'en prendre une autre. Elles sont une condition d'invention qui prend en compte l'épaisseur et les effets de superpositions du travail scientifique et du travail philosophique. Les alliances ne sont pas simples et linéaires. La condition de ces alliances est que l'homme ne s'y donne pas comme élément réversible de chaque science, une fois chercheur, une fois mécanicien, une fois philosophe en cherchant un commun dénominateur. L'homme est générique, indépendant de chacune de ces perspectives, qui sont comme autant de sujets qui se forment en faisant la science ou d'autres savoirs.

RETOUR SUR L'HOMME GÉNÉRIQUE

L'épistémologie générique impose un décollement entre l'homme quotidien pris dans l'une ou l'autre discipline et l'homme condition de ces sujets philosophiques, mais ne se confondant pas avec eux. L'homme est celui qui, à la fois, peut concevoir les sciences et peut philosopher. Mais pour cela, il faut un ordre, entre homme générique et sujet, il faut, pour le philosophe comme pour le concepteur, toujours un élément de réel, qui ne fasse pas partie de ses données d'origine, mais qui l'amène à transformer ce qui était endogène, à défaire les hiérarchies, à mettre en place des procédures où chaque discipline ait sa place, mais de façon décentrée. En déconstruisant la notion d'intention en trajectoire, supposant orientation, qui peut être, selon les niveaux, forme et formalisme – de l'esthétique à l'épistémologie-, intuition et extension ou conjecture – de l'épistémologie à l'esthétique, mais vues comme DSD. L'homme générique est indépendant de ces trajectoires, elles peuvent être aussi multiples que l'on veut, au sens où bien des trajectoires scientifiques possibles.

QU'EN EST-IL DE LA QUANTIQUE ?

Nous avons traité presque exclusivement de biologie, alors que Laruelle propose la série, générique, quantique, philo-fiction. Nous avons montré comment la constante générique modifie les sciences et les rapports entre les disciplines. La quantique rompt les continuités, porte non sur les choses, mais sur les états et les opérateurs, elle permet le traitement matriciel. Il nous faudrait compléter en montrant comment l'élément NIM (nombre imaginaire) permet de faire tenir les superpositions. La biologie rompt aussi la continuité en se présentant comme une multiplicité de disciplines. La fiction est nécessaire pour orienter l'organisation de la recherche entre de multiples disciplines, et éventuellement, faire de disciplines émergentes sur fond interdisciplinaire, une DSD. Mais ce n'est pas un simple retournement, il faudrait un élément extérieur pour qu'un tel projet donne des résultats.

La biologie est ici comme l'un des objets intégratifs rendus possibles par le générique, la quantique et la philo-fiction.

Ainsi on n'oppose plus l'universalité de la science à la particularité de l'action de l'homme, une localité se construit, où démocratie des disciplines, intimité collective et DSD sont les conditions mêmes du travail scientifique.

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Liste complète des publications de la chaire TMCI 2019

Axe 1 : Théorie de la conception et raisonnement dans l'inconnu

1) Elmquist, M., Gawer, A. and Le Masson, P. (2019). Innovation Theory and the (Re)foundation of Management: Facing the Unknown. European Management Review, 16(2):379–381, June 2019.
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