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2nd October to 30th November 2017

Keynote address

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for Coping with Intractable Complex Phenomenain Economics and Social Science:
Deep Complexity

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A Cognitive Behavioral Modelling for Coping with Intractable Complex Phenomena in Economics and Social Science: Deep Complexity

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July 2017

Abstract

It is argued in this paper that there is an issue of complex phenomenal intractability in economics, in particular, and in social science in general, and that it is unduly neglected in theorizing in these areas. This intractability is complex because it is an offspring of certain complex phenomena. It is phenomenal because it relates to empirical phenomena, which distinguishes it from conceptual and computational approaches to intractability and complexity. Among the possible reasons for this neglect, one is, in established complexity theory, the focus on computer simulations which seemingly solve for analytical sources of intractability. Another one is the relegation of intractability proper to theoretical computer science. Yet the empirical inquiries that originated this research reveal significant cases of intractable complex phenomena that are accommodated neither by existing complexity theory nor by the theory of computational intractability. The task ahead is therefore to construct a theory of complexity with phenomenal intractability. A reflexive cognitive behavioral modelling is developed and tested through its application. It results in what may be called a Deep Complexity Procedure. Its implications for economic and social theorizing are discussed.

Keywords: Phenomenal intractability, cognitive behavioral modelling, reflexivity, non-commutative complementarity, procedural theorizing, Deep Complexity Procedure.

JEL classification: B0, B4, B5

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1. Introduction

This paper addresses the problem with theorizing that originates from significant empirical occurrences of intractable complex phenomena in economics, particularly, and in social science, generally.[1] Intractability denotes an unresolved difficulty of solving effectively a problem. Although this kind of difficulty is not rare in these areas, as will be documented in this paper, and although it is acknowledged that intractability is one of the properties that "complexity" connotes, "singly or in a melange" with other properties (Albin, 1998: xiii) such as system's intricacy, radical uncertainty, and uncontrollability, a peculiar fact is the quasi absence of the term "intractability" from theoretical developments in economics and social science. Its use seems restricted to conflict resolution thinking, on the one hand, and to theoretical computer science and computational complexity on the other hand. In the former, a notable instance is Donald Schon and Martin Rein's thinking on intractable policy controversies, where intractable problems are those that are "immune to resolution by appeal to the facts of the situation" (Schon and Rein, 1994: 3). In the latter, intractability is *computational*. It denotes an unresolved difficulty of solving a problem of computation. It is the main way, in addition to the former, in which intractability is present in economics and social science, through computational economics and computational social science. However there are notable exceptions in which intractability is addressed as a specific theoretical issue in these areas. One is K. Vela Velupillai's focus on the logical and mathematical foundations of mathematical economics, and on computable economics (Velupillai, 2005, 2009, 2010; Velupillai and Zambelli, 2011). The other one is Herbert Simon's research program on decision making and problem solving in which procedural rationality appears closely connected with what intractability designates, although Simon seemingly did not use this term (Simon, 1976).

It is my own experience with an unresolved difficulty in an empirical research in economics that triggered my interest for intractability and complexity theory (Delorme, 2010). And it is the search of a case study with a clear-cut evidence of intractability in a domain less exposed to inconclusive debate, as economics often is, that drove me to investigate this issue in safety science. A similar difficulty was diagnosed in road safety governance at the country level (Delorme, Lassarre, 2014). It was found that this specific difficulty was not satisfactorily grasped through the conventional scientific toolkit in use in this area. Yet it was, and still is, robust and significant. It denotes a situation of complexity with a *phenomenal* intractability.

I attempt in this paper to move beyond the inevitable case specificity of these findings, and to model complex phenomenal intractability in a constructive way. I argue three things. First, there exist empirical, concrete manifestations of intractability closely connected with various complex phenomena in economics and social science more generally. Although these manifestations of a complex phenomenal intractability may be significant, they remain broadly unnoticed or neglected and trivialized, that is, made seem less significant than they actually are. Second, complexity with nontrivial phenomenal intractability can be modelled constructively. A model is developed on the basis of an alternative frame of reference which subsumes the classical frame of reference. Third, this modelling is encompassing. It may help avoid the overconfidence in the effectiveness of theory that economics and social science often harbor through a usual way of theorizing that deprives itself of, or excludes, the possibility of nontrivial phenomenal intractability.

This modelling brings a toolkit for dealing with intractable empirical problem situations. It might open up a debate about its rather far reaching implications for the style of theorizing based on empirical research, in economics and social science, whenever the possibility of complexity with phenomenal intractability is not assumed away from the outset. Two of these implications are a

[1] The term « economics » is used as a shortcut for economic theorizing in order to gather together the often separated perspectives of economics *stricto sensu*, and of the political economy style of theorizing. Differentiating "economics" and "social science" does not imply that the former is not a part of the latter. It is simply meant to signal that the point of departure of this paper lies in economic theorizing. It was complemented with a case study in safety science, which is a socio-technical area, and was ultimately extended to social science as will be developed in the paper.

positive reassessment of John Maynard Keynes's methodological revolution in economics, and a reaffirmation of the profound relevance of Herbert Simon's cognitive behavioral approach to decision making and to scientific practice in social science.

The paper is organized as the unfolding of a cognitive process inspired by Simon (1976: 132). It is based on a sequence of stages that range from learning and the need for theorizing phenomenal intractability, or problem formulation (section 2), to theorizing phenomenal intractability, or problem solving (section 3), and finally to characterizing a procedure (Deep Complexity) for dealing with complexity with nontrivial phenomenal intractability, or concept attainment (section 4), with concluding remarks in section 5.

2. Problem formulation

Formulating the central issue at stake will necessitate moving from the empirical experience of intractability to complexity with nontrivial phenomenal intractability and the need to theorize it.

2.1 Intractable complex phenomena in two case studies

2.1.1 Public expenditure and institutional patterns at the country level

This research was triggered by the results of a comparative empirical inquiry on the long run determinants of public expenditure and their evolution in France and Germany (Delorme, 2010). The analysis was initially quantitative. Its development proved the necessity to integrate qualitative factors. The main finding was the uncovering of robust institutional arrangements, slowly evolving over time, and characterizing interactions between the state and the economy, beyond the duality of government and market. These institutional configurations were found to be history and context dependent, with commonalities and strong specificities across the two countries, which led to define them as specific Regimes of Interactions between the State and the Economy (RISE). This finding proved ex post to be broadly congruent with the institutional Theory of Regulation as exposed by Robert Boyer (2015), but it was in no way an outcome of this theory taken as a predefined hypothesis. Then the RISE stands as an empirical conjecture with a monographic status and without any previous reliance on a well identified theory. Therefore, it raises several questions. What is its bearing beyond the two cases that were compared? How to take into account the very intricate and robust combinations of commonalities and specificities that make up the RISEs? It suggests an enabling and constraining framework. Then how does it connect with economic policy making? And how does it connect with existing theory? Institutionalist theories such as the Theory of Regulation or the approach of institutional complementarities (Amable, 2016), though appealing, are too general to bring answers to these questions. Yet, none of them can be answered without a theoretical characterization. This lack of an underpinning theory is an unresolved difficulty of explaining the RISE that makes it intractable.

2.1.2 Road safety governance at the country level

The next stage of this research is based on a comparative study of road safety outcomes between France and Great Britain (Delorme, Lassarre, 2014). These outcomes are measured by the number of fatalities. They differ neatly between the two countries, but in a special way. To detect it, it is necessary to rely on the rather unambiguous indicator commonly used in international comparisons that consists in the mortality risk measured by the number of fatalities per vehicle-kilometer. The intriguing feature is that the ratio of the French to the British mortality risks has remained practically constant at an average level of 2 since the inception of road safety statistics in the 1950s. The most recent figures, those for 2015, do not disconfirm it (IRTAD, 2016). Yet, in spite of this gap, road safety steadily improved in both countries over the whole period, along roughly parallel declining trends of fatality rates. In 2015, it amounted to about 6 fatalities per billion vehicle-kilometer in France, and to about 3 in Britain. The gap can be quantitatively explained by differences in exposure to four risk factors: speed, alcohol and driving, protection in vehicle, and urbanization (Delorme, Lassarre, ibid.). But there is no explanation of its persisting, long lasting and nearly constant character, despite policy actions on these factors in both countries. There are also qualitative studies. But they are focused either on particular aspects or on general ones, such as a cultural difference between British and French road users, and remain either too specific and piecemeal or too general, without any integrative perspective that would allow to articulate them with the quantitative insights in a unified setting appropriate to the global character of the gap. Underneath it, there must be some constantly operating factor or factors not captured by existing analyses and left untouched by the road safety actions and policies targeted on the classical risk factors, and that have been implemented in France throughout this six decade period. Therefore, addressing this gap through existing analyses confronts us with an unresolved difficulty. It appears intractable.

2.1.3 The decision not to trivialize intractability

Several objections to the intractability that is detected in these two case studies can be envisaged. If they were convincing enough, they would justify neglecting, assuming away, ignoring, neutralizing or, to sum up, trivializing intractability.

An immediate objection to taking intractability as a serious challenge might be that it is the consequence of a neglect of the contributions of the complex systems approaches both in economics, with agent based computational models, and in safety science (Goh et al., 2010; Larsson et al., 2010; Dekker et al., 2011). The point is that however suggestive these approaches may be at a general theoretical level, none of them, to this author's knowledge, brings a substantive help to the specific empirical issues at stake here.

Other more specific objections can be found against the intractability that appears in the first case study. One is its excessive case specificity. According to another one, its subject matter is irrelevant to economics strictly understood and pertains more to political economy or political science. A third objection might be against its destructive character since there is seemingly no way to address it in classical science. Then it would be advisable to trivialize intractability and remain focused on addressing issues for which the available analytical toolkit works. Its corollary is for the researcher to wait for future progress in scientific economics to solve it. A final objection points to the researcher's possible incompetence or unknowability of the existing theoretical literature in economics. An unsurprising response is to expose research to public criticism.

Fortunately enough, the road safety case avoids most of these objections apart from the case specificity problem that will be addressed later. Road safety avoids the endless debates about the tools used, the assumptions made, explicitly or implicitly, the quality of the data, the doctrinal orientations, etc., that one finds in nontrivial issues in economics and which tend to render it broadly non-demonstrative and non-conclusive, as J.M. Keynes noticed several decades ago (Delorme, 2013). Things go differently in road safety. Numbers killed can hardly be disputed even when they cannot be explained satisfactorily with classical analytical tools. And when the issues that are unexplained are important, they cannot be indefinitely left to future progress in scientific research. Real life events impose that some action be taken. In this case, intractability cannot be disposed of by "as if" or "all other things equal" assumptions.

Coming back to theoretical and empirical economics, how could it ignore intractability when it is proposed to acknowledge it in theoretical physics (Wolfram, 1985)? It is a nontrivial intractability that appears in both case studies. It needs to be studied in its own right.

2.2 Nontrivial intractability in the complexity landscape

The decision to address frontally nontrivial intractability in theoretical work in social science is challenging. H. Simon's decision making pattern is both appealing and in need to be discussed. The intractability it integrates through procedural rationality pertains to agent's decision making in situations which are de facto at a small scale in comparison to the large scale phenomena that are involved with the RISE and the gap in road safety. Therefore it could hardly be applied directly to these case studies. However it invites to reflect further on the implications of extending it to the scientist taken as a Simonian decision maker, which will be developed in section 3.

K.V. Velupillai suggests a "Linnean" or natural historian attitude for the student of intractable phenomena in which the main tasks would be "to classify and systematize particular intractable [phenomena] in increasingly and morally transparent ways" (Velupillai, 2005: 868, 870). This, including transparency, is what was done in Delorme (2010). It was a necessary first step. But it is not sufficient in view of the questions raised above. They call for moving beyond this initial stage, which is what is attempted here.

At this point we are brought back to complexity theory as a framework for studying intractability. It invites us to examine where nontrivial intractability stands in the complexity literature. In the plurality of approaches to complexity, a useful distinction is between dynamic and computational complexity.[2] In short, dynamic complexity refers to the behavior of dynamical systems made up of numerous nonlinear interactions between heterogeneous components with generally unpredictable outcomes. Computer simulation has become the central procedure for dealing with this high level of intricacy. It is deemed to render tractable those problems that cannot be solved analytically. Therefore, in this kind of setting, intractability becomes solved by definition, and any further concern for it is likely to be wide of the mark. It is an approach, notably as agent-based modelling, that aspires to reshape the way complex phenomena are addressed in social science.[3]

Computational complexity refers to computational complexity theory, a branch of the theory of computation in theoretical computer science and mathematics that focuses on classifying problems according to the difficulty of solving them both in theory and in practice. A central issue is how the number of steps or the time it takes to solve a problem grows with the size of the input. Problems that can be solved by a computer using no more time than some "slowly growing" function of the size of the input are called "tractable". Polynomial functions are "often [taken] to be "slowly growing" while functions that grow faster than any polynomial are deemed to grow too fast". Problems that can be solved in theory, even in large but finite time, "but which in practice take too long for their solutions to be usable" or efficient are said to be intractable (Hopcroft et al, 2007: 5, 368). Then computational intractability denotes an unresolved difficulty of performing the computation needed to solve efficiently, i.e in polynomial time, generally, a given problem.

At this point it seems problematic to apply directly these perspectives to the case studies at stake here. Yet a distinction between them must be made. On the one hand most of the models of complex systems to which dynamic complexity belongs are used to display general complex behavior, not to model specific empirical systems or phenomena. Then it is no surprise that a phenomenal complexity

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[2] J.B. Rosser Jr. (2009).

[3] L.Tesfatsion (2003, 2005), L. Tesfatsion and K.L. Judd, eds, (2006), R. Conte et al. (2012), W.B. Arthur (2015).

experienced or observed empirically with specific phenomena remains foreign to models of general complex behavior of systems. On the other hand there seems to be a close parallel between computational intractability and the intractability experienced in the present research, that is, a parallel between performing a computation and building an explanation. It will be discussed later on.

However this way of depicting the complexity literature fails short of providing an accurate picture of it. It ignores a rich philosophical and methodological thinking on complexity. It also ignores second order cybernetics or the "cybernetics of observing systems" (Von Foerster, 2003). And it excludes de facto a plurality of contributions to the study of complexity which cannot be ranked among the computer generated complexity and the logical-computational limits to knowledge, on the one hand, and that do not reduce to philosophical and second order cybernetics on the other hand. Most of these contributions are inquiry driven and aimed at empirical problem solving. This creates a rationale for calling them phenomenal. They differ neatly from the focus on a conceptual view of complexity that can be found in philosophical thinking and second order cybernetics. The research leading to this paper falls in this phenomenal category.

At this stage, it is four broad perspectives on complexity in social science that need to be differentiated: dynamic, computational, conceptual, and phenomenal. Still, this has to be complemented by taking into account the status of intractability, trivial or nontrivial, in conceptual and phenomenal complexity. On the whole this brings a characterization of six approaches. A synthetic presentation of them is given in Table 1, without any pretense at exhaustiveness.

[Table 1 about here]

Each approach is characterized in terms of its domain of application, its main focus or goal, the particular status of intractability, its possible contribution to the present research, and the issue that it leaves pending. A way to structure complexity which follows from the approach developed here is to consider that it combines intricacy with intractability, the latter ranging from nil or very low levels, as is the case with dynamic complexity, to significant levels in other contexts. Intractability covers all cases of an unresolved difficulty of solving a problem, be it a problem of computation, of control, of probabilistic prediction, or of explanation. Intricacy is ever present whereas intractability can be "active", that is nontrivial, or not. Intricacy is therefore not discriminating and not made apparent in the table, for the sake of simplicity. On the other hand the status of intractability is fully discriminating. It renders necessary to distinguish conceptual complexity with trivialized intractability symbolized by T, from conceptual complexity with nontrivial intractability, symbolized by NT. The same goes for phenomenal complexity T, or NT. Although Table 1 is necessarily a simplified presentation, most of its cells seem explicit enough to be dispensed from systematic comments. Dynamic and computational complexities were evoked above. The former relates mainly to complex adaptive systems and agent based models of simulation with such representative authors as J. Holland (2002), W.B. Arthur (2015), J.M. Epstein (1999), L. Tesfatsion (2006). It also relates to evolutionary complex systems (P. Allen, 1994; J. Foster, 2005). The latter is classically in the tradition of Gödel and Turing. Contributions by G. Chaitin (2006), S. Wolfram (1985), P.S. Albin (1998), and K.V. Velupillai (2010) illustrate it.

Conceptual complexity follows from philosophical and methodological systems thinking, and from complexity thinking. The status of intractability divides it in two branches. One, "Conceptual T" is silent on intractability. It includes notably classical systems thinking (von Bertalanffy, 1968) and sparse philosophical thinking (McIntyre, 1998, Allen, 2001). The other one or "Conceptual NT" addresses both philosophical and methodological limits to knowledge (Morin, 2008 ; Cilliers, 2005 ; Hayek, 1967, 1975; Prigogine and Stengers, 1984; Le Moigne, 1990 ; Richardson, 2008 ; Tsoukas and Hatch, 2001) and second-order cybernetics (von Foerster, 2003). Although it integrates nontrivial intractability and a critical reflection on the limits of knowledge, it remains programmatic and at a distance from theoretical and empirical problem solving.

This impediment should be remedied in principle by phenomenal complexity and its orientation towards empirical problem solving. This perspective gets also divided in two parts by the status of intractability. Its “Phenomenal T” part, with trivialized intractability, characterizes several perspectives in the systems approach to empirical issues. One finds this kind of complexity in H. Simon’s architecture of complexity which solves for the intricacy of nearly decomposable systems. One also finds it in organization studies (McKelvey, 1999), in sociology (Byrne and Callaghan, 2014), and in safety science (Dekker et al., 2011; Goh et al., 2010; Larsson et al., 2010).

There is finally a particular region of this complexity landscape in which complexity is addressed without relying on any of the five approaches reviewed thus far. Its common trait is phenomenal complexity with nontrivial intractability. This “Phenomenal NT” part includes the present research on the RISE and the gap in road safety. A more detailed appraisal appears in Table 2.

[Table 2 about here]

An immediate lesson of Table 2 is that nontrivial intractability is not an exotic notion that would be limited to our own research. Table 2 provides a list of approaches which originate in particular dissatisfactions with the conventional methods ruling in a variety of disciplines and areas of inquiry, and in the search for alternatives to them. In each instance it amounts to the recognition of an unresolved difficulty of explaining significant problems with the tools and methods that are in conventional use in the respective areas. And it amounts to a constant practice of not trivializing it. Each response is the way to deal with nontrivial intractability that is worked out by every author in her/his respective area of inquiry. It is also, incidentally, a way to define heterodoxy, with the implication that this list is illustrative and partial, notably in economics where heterodox approaches such as original institutional economics and Post-Keynesian economics, and contributions such as Thomas Piketty’s (2015) might integrate the list.

Unfortunately, the nontrivial intractability shared by the approaches in Table 2 is an unnoticed and unexploited commonality. The consequence is that they are isolated from each other and, above all, are case specific in the absence of a theory of nontrivial phenomenal intractability. A partial exception to case specificity is Simon’s research program. It is both on the trivial or resolved side of phenomenal intractability with near decomposability as a solution to the complexity of hierarchical systems (Simon, 1962, 1996), and on the side of nontrivial phenomenal intractability with Simon’s decision making pattern based on the distinction between substantive and procedural rationality (Simon, 1976). It is useful for small scale problem situations but it is problematic for large scale phenomena such as the RISE and the gap in road safety, which are likely to embody greater intricacy and less decomposability than the examples Simon studies. All in all, these approaches do not inform on concrete issues that lie outside their specific areas of inquiry. Yet they provide a general support to inquiry-driven and heuristic search. They all follow a procedure of research in which concrete problems come first rather than making what will be studied and how it will be addressed totally dependent on a formal conceptual and technical toolkit, conventional or not, taken as given and prior to problems.

2.3 Needed: A theoretical characterization of phenomenal intractability

2.3.1 First lessons about phenomenal intractability

A first lesson is that the initial question of an underpinning theory for the two case studies remains unanswered. We cannot satisfy with staying at a Linnean stage. If we wish to devise a theory for these subject matters, we have first to render nontrivial phenomenal intractability more intelligible through theorizing it. This task appears prior to theorizing our empirical findings. Next, nontrivial phenomenal intractability in social science is not accommodated by complexity science, not by complexity thinking, and not by systems thinking in their present state. Thirdly, there is a paradox about intractability in the history of economic thought. Beyond the instances evoked in Table 2, the presence of what intractability stands for in the historical development of economic analysis is mentioned by several authors under the term of complexity. It started with replacing "a computationally intractable" problem by the "computationally simpler problem of calculating a posited equilibrium of the economic system" with A. Smith, T. Malthus, and D. Ricardo (Foley, 1998: 54-55). Further developments (Colander, 2009; Delorme, 2013) can be viewed as reactions against what was perceived as a doctrinal body unable to tackle the issues pertaining to the "overwhelming complexity of the economy" (Hoover, 2008), which is a way to define heterodoxy. But intractability remains not named and therefore not acknowledged as an issue to be studied in its own right although many heterodox perspectives rely de facto on research attitudes and on properties of their subject matters that are constitutive of a phenomenal intractability.

2.3.2 What is expected from theorizing nontrivial phenomenal intractability

Theorizing phenomenal intractability needs to be first a theoretical characterization, that is, a set of ideas and propositions holding together in a systematized way, not case specific, not too general and unable to grasp specific empirical phenomena, not merely conceptual, and yet containing an explanatory mechanism rendering intelligible specific empirical problem-situations, and being implementable and testable.

Specifically, this theory is expected to deliver two things. It is first to provide the resources for establishing a dividing line between phenomenal problems that can be resolved and those that cannot. Let us call it the first requirement. A second requirement is to provide the means for studying how to cope, and for effectively coping, with intractable phenomenal problems.

2.3.3 Phenomenal intractability and computing

There is an apparent parallel between the first requirement and the theory of computational intractability exposed by J. E. Hopcroft et al. It consists in "techniques for showing problems not to be solvable in polynomial time" and for studying "the dividing line between problems that can be solved in polynomial time and those that require exponential time or more" '(Hopcroft et al, op.cit.: 425). One might detect a superiority of the accuracy that computational intractability supposedly entails over the non formal character of phenomenal intractability. This would nevertheless understate that what computational intractability means in practice is open to debate for its borders were "redefined continuously" (Paun, 2008: 347). A polynomial time algorithm is not always practical if its running time is very large, and may become useless except on small instances. Similarly, some non polynomial problems can be solved in reasonable time on small instances.

Another issue is about the meaning of “computational” and “computation”. Computation has evolved from “the mechanical steps followed to evaluate mathematical functions” and the “study of phenomena surrounding computers” to the “modern catchphrase: Computing is the study of information processes, natural an artificial” (Denning, 2010: 371). Computing means processing symbolic structures and not just numerical data (Newell and Simon, 1976). Then, to compute is to process information in a sequence of representations (patterns of symbols that stand for something) in which the transitions from one element in the sequence to the next are controlled by a representation (Denning, ibid.). To think computationally is to think in terms of problem solving, that is, to interpret a problem as an information process and then seek to develop a reasonable course of action, a procedure, a method, or an algorithmic process leading to what can be viewed as a solution. This does not imply an “entirely computational view of economic behavior” (Latsch, 2003: 391) where “computational” is taken in its narrow sense. The extended view of computing has a large bearing and is practically synonymous with cognition, the processing of symbols. If computing is taken in its formal numerical sense, then our empirical findings are clearly computationally intractable for the present time computing capacities and one cannot know if they will ever be computable in polynomial time. But if computing is taken in its extended sense, then it signals a call to all relevant cognitive resources rather than staying restrained to formal mathematical tools. It is what is developed below.

2.3.4 Phenomenal intractability and complexity

We are finally driven back to the subject matter of problem solving. It is ultimately to render more intelligible our empirical findings of complex phenomena with nontrivial phenomenal intractability. But this final point cannot be attained without going through the preliminary step of solving the problem of a theoretical characterization of phenomenal intractability.

3. Problem solving

The problem to solve is to meet the two requirements that were mentioned above. It is first to explain the dividing line between the tractable and the intractable, and secondly to devise a mechanism for dealing with the intractable. But before a research strategy for meeting the former and modelling the latter can be developed, it is necessary to make explicit the frame of reference that shapes both of them through a set of fundamental assumptions and concepts holding together and informing the research strategy followed and the modelling ensuing from it.

3.1 An alternative frame of reference

3.1.1 Problems first

The task pursued here is no exception to Joseph Schumpeter’s assertion that “analytic effort is of necessity preceded by a preanalytic cognitive act that supplies the raw material for the analytical effort” and that he calls “Vision” (Schumpeter, 1954: 41). The “vision” adopted here is that problems, rather than theory, come first. It has illustrious predecessors. One of them is Keynes who mentions in his *General Theory* “the extreme complexity of the actual course of events” and his search of “a less intractable material upon which to work” in order to give convenient expression “to actual phenomena of the economic system (…) in which we live” that are “coloured by certain special characteristics (…) but which are not logically necessary” (Keynes, 1936: 249). Another inspiring source is Simon’s scientific attitude. His "the problem comes first" translates in a disrespect for disciplinary boundaries: "If it forces to step outside them, so be it" (Klamer, 1992: 888). It also translates in the research pursued here through searching how the unresolved difficulties experienced might be due to the limitations of the technical and methodological frameworks in use in the respective disciplines and to the "theory first" or "technical formal apparatus first" conventional attitude. It invites to view "intractable" as "intractable with the available tools" and to search how to conceive alternative tools for making the problem less intractable.

This problem-first attitude introduces a sort of asymmetry with its alternatives. It means that the first step of inquiry is to assess whether the problem can be grasped with the existing theoretical or technical toolkit whereas the alternative view excludes or trivializes intractability de facto, except for computational intractability. This primary cognitive act is encompassing to the extent that it does not exclude the issues that the conventional toolkit accommodates, and includes issues not accommodated by it. This entails a continuity with the conventional toolkit through the constant initial standpoint of asking first whether a given problem can be satisfactorily addressed with the existing toolkit, that is, whether it is tractable or not. If it is tractable, then we can proceed with the existing toolkit. If it is not tractable, then it invites to reflect on an alternative toolkit. At stake here is how one proceeds to detect the intractable. It calls for a cognitive behavioral setting.

3.1.2 A frame reflective Simonian setting

The reference to a Simonian setting finds its inspiration in Herbert Simon describing Simon the scientist as problem solver and satisficer (Simon, 1991: 368, 385). Simon applies to himself the cognitive behavioral research program that he developed for the study of problem solving by decision making agents. It includes the notions of rational behavior as process, of heuristic search, of aspiration level, and of satisficing. Rational behavior is substantial when it is defined by the "what", the outcome of the application of a given procedure; it is procedurally rational when it relies on the "how", the procedure itself (Simon, 1978: 494). The former rests on the application of existing tools to solve a problem. The latter relies on deliberation in problem situations "in which the subject must gather information of various kinds and process it in different ways in order to arrive at a reasonable course of action, a solution to the problem" (Simon, 1976: 132). Substantive rationality is appropriate to well defined, probabilizable, and decomposable or nearly decomposable problems. Procedural rationality is appropriate to ill defined, radically uncertain, and hardly decomposable problems, problems that arise in situations that are not "sufficiently simple or transparent to [the] mind" (Simon, ibid.: 144). Then problem solving consists in the search for optimal (substantively rational) or satisficing (good enough) solutions within a search space bounded by constraints and informed by an aspiration level and heuristics.

This setting makes up the frame through which Simon studies agents' decision making and describes his own scientific practice. It provides a guideline for the search of a reasonable course of action in problem situations that appear intractable, and, therefore, it seems suited to the issue at stake in this paper. There is however a big difference which originates in the sizes of the subject matters. The decision making Simon studies lends itself to realistic observation, to laboratory style experimentation, and to replication of individual agents' behavior. These are elements that can be gathered to explain Simon's empiricist scientific practice, a position he acknowledges in a footnote, after having termed it positivist (Simon, 1996: 5). We are dealing here with large scale phenomena. Although empirical realisticness is all right, experimentation seems out of reach for them. And their uniqueness makes matters worse. Therefore the Simonian setting that can be appropriate for our problem cannot rely on Simon's empiricist criteria. As alternative criteria are not readily available, the Simonian setting has to be thought of within a new frame that can accommodate the study of phenomena that do not lend themselves to purely empiricist criteria. A frame reflective practice is called for as "an activity intended to explore other "ways of seeing" than those presenting themselves as the most evident explanation" (Yanow and Tsoukas, 2009: 1359). This view defines the frame reflective Simonian setting introduced here.

3.1.3 A reflective epistemology of scientific practice

By definition, intractable problems do not come to us as well formed problems of instrumental choice to which an available technical and scientific apparatus would be immediately applicable. They tend to present themselves, on the contrary, as problematic situations. To convert an intractable problem situation into a tractable or less intractable one starts with a problem-setting process in which the ends and means that are deployed are reciprocally determined, subject to a constraint of scientific practice. This is what was done above. This frame reflection opens the way to an epistemic shift from addressing an observed subject matter from outside, by an observer external to it, to addressing the interaction of an observer with the observed subject matter. It invites us to move beyond the conventionally held, ingrained empiricist mode of explanation and to engage in a search process. It is the extension to scientific practice of what D. Schon, building on James Dewey's view, describes as a reflective epistemology of practice (Schon, 2001). Whereas Simon could deliberate and satisfice with the application of an available procedure based on empiricist criteria that are appropriate to small size issues, we need not only to deliberate but also to construct a satisficing procedure whose criteria of validity will have to be explicit.

The empiricist/positivist epistemology of scientific practice now seems to rest on a particular view of science, one focusing too exclusively on prediction and the unity of scientific method (Scheall, 2015: 228). The focus on the unity of scientific method introduced the belief that doing science could be equated with an exclusive method. This equation is confusing. To move beyond it necessitates to draw a distinction between doing science, and various modalities of doing science. It sets a constraint for scientific practice. Whatever the method used, one must abide by doing science, whose substance follows from a widely shared practice, that is, a "form of activity specified by a system of rules (…) which gives the activity its structure" (Rawls, 1955: 3).

Pragmatically, scientific practice is an activity of production of knowledge which combines five specific elements: it is about some object or subject matter pertaining to some reality, it aims at some truth value or validity, it relies on an explicit conceptual and methodological framework, it is systematically exposed to public criticism and testing, and it is subject to error and revision.

3.2 Complexity conceptualized

It seems that characterizing a frame of reference for dealing with intractable complex phenomena can hardly be carried out without a clear definition of the concept of complexity it uses. Yet, this appears to be a challenging task. Complexity is a term that "means different things in different disciplines, and is not rigorously defined outside of a specific context" according to the glossary of the Santa Fe Institute Complexity Explorer (retrieved on February 16, 2017). This view finds a confirmation with the responses given in a book by 24 contributors with an expertise in complexity, including a majority of scientists, who were asked to define complexity (Gershenson, ed, 2008). The editor was led to conclude that the "most common problematic aspect of complexity was the misuse of the concept" (ibid.: 135).

A lesson of modesty follows from this state of affairs. In the context of this paper, we need a concept of complexity that captures the features of intricacy and intractability and does not exclude any of the diverse perspectives that were exposed above (Table 1). It ensues that complexity is neither intrinsic to some object "lying in the world out there" nor subjective, because it always pertains to the interaction between an inquiring subject (observer, computer, controller) and an object of inquiry. In most cases it arises out of a many-sided problem situation in a given context (intellectual, occupational) at a given point in time. There follows from these considerations that the complexity of interest in our context pertains to a problem-situation.

Another lesson is that two fundamental features need to be integrated in its definition. First, complexity is not reducible to either intricacy or intractability. Both are present, at various levels ranging from low to high for the former, and from nil (tractability) to high for the latter. Second, complexity is not reducible to a property of a subject matter independently of the interaction with an inquirer as well as it is not reducible to a subjective property of an inquiring subject independently of the interaction with the subject matter.

These elements and the discussion of the previous section are summarized in Table 3.

[Table 3 about here]

Therefore two things need to be taken into account. One is intricacy, or the computation problem in the case of computational complexity. The other one is intractability. Then, each one of the four perspectives on complexity is structured in terms of a combination of intricacy, or the computation problem, on the one hand, and intractability, theoretical and practical (empirical, experiential), on the other hand. The phrase "intractable in principle" signals the reciprocal means/ends adjustment from which follows the decision to trivialize or not intractability. The cases which triggered this paper appear at the bottom line of phenomenal complexity. They combine a high level of intricacy with an unresolved difficulty of solving it both in theory and in practice.

A definition which covers and condenses the properties shown in Table 3 appears as follows. Complexity is a combination of intricacy - or of a computation problem - with the difficulty of solving it, this combination arising out of the interaction of an inquirer with a subject matter.

3.3 Situation recognition and the dividing line

The criteria for characterizing the problem-situations in the two case studies follow from the frame of reference and the conceptualization of complexity. The way they operate is shown in Table 4. Lines 1 to 5 represent the problem-first position and the interaction between operator and subject matter. The combination of intricacy and intractability ending in a judgement of satisficing shows up in lines 6 to 9. The resulting character of the situation (line 10) is dependent on these nine dimensions.

[Table 4 about here]

Two things must be noted. One follows from moving from a context of general definition of complexity in 3.2 to the present context of situation recognition. The theoretical/practical distinction for tractability/intractability in the former becomes adjusted to the cognitive behavioral setting in the latter with a substantive/procedural distinction. It forms the basis for the judgement of tractability/intractability in terms of satisficing. This process is subjected to the constraint of scientific practice exposed above. Satisficing is therefore not individually subjective. It operates at the community level. The other thing relates to the benefit of having an encompassing frame of reference. It enables an open ended recognition of situation and an endogenously determined dividing line or tipping point between what is and what is not complex-with-nontrivial-phenomenal-intractability. It appears in the move from line 9 to line 10. Complex nontrivial phenomenal intractability does not imply that all other cases denote non-complex situations. Such situations range from complex without nontrivial phenomenal intractability, that is to say, with trivial intractability or plain tractability, to complicated or simple, in function of the combined nine dimensions.

3.4 Mechanism: The building block

The cognitive behavioral process of situation recognition developed above offers a basis for expressing intractability formally in a first step, and operationally in a next step.

3.4.1 Formal intractability

Intractability is expressed in terms of the resources, cognitive and behavioral, that are available or required for performing satisficingly a given task, in a given activity, at a given point in time, and subject to the standard of good practice in use in the activity, here, the standard of scientific practice that was presented above. In this setting, intractability involves an aspiration level, satisficing, the cognitive and behavioral resources available at a given point in time, and the standard. To symbolize each of these terms, we refer in a generic way to letter D standing for the level of difficulty measured by the level of resources that is required or is available for dealing with each of them. Then, both intractability and tractability depend on the level of resources that are required for satisficing. A problem situation is intractable if the level of resources that are necessary to address it satisficingly is strictly larger than the level of resources that is available, and smaller or equal for a tractable situation. The level of resources required for satisficing cannot be larger than the aspiration level, otherwise it would be absurd. And, for intractability to hold, they cannot be lower than the available level of resources. Otherwise it would mean not using all available resources. Intractability and tractability are expressed formally below, with all magnitudes being positive.

$$\text{Intractability:} \quad \widehat{D}_{i,t} \geq D^{s}_{i,t} > \overline{D}_{t} \quad \text{subject to} \quad \widehat{D}_{i,t}, D^{s}_{i,t} \geq D^{*}_{j,t}$$

$$\text{Tractability:} \quad \widehat{D}_{i,t} \geq D^{s}_{i,t} \leq \overline{D}_{t} \quad \text{subject to} \quad \widehat{D}_{i,t}, D^{s}_{i,t} \geq D^{*}_{j,t}$$

Symbols $\widehat{D}$: aspiration level, resources required for meeting it

D^{s}: level of resources required for satisficing

$\overline{D}$: available level of resources, given at t

D^{*}: standard of good practice, resources required for meeting it

i: task

j: activity context

s: satisficing

t: time

3.4.2 Dynamics of intractable complexity

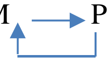
Complexity with nontrivial phenomenal intractability or, in short, intractable complexity, involves more than formal intractability and the place of satisficing in it. Satisficing highlights the community-operator judgement. More generally, the cognitive behavioral setting provides a background for deliberating in contexts of ignorance and radical uncertainty, rather than applying algorithmic tools devised for contexts that are free of these limitations. Procedural rationality provides simple, yet powerful directions for action in situations in which substantive rationality seems inappropriate. But they are mere directions. When it comes to concrete research on topics less prone to experimentation and simplification than individual decision making, one may wish to work with more specified tools and mechanisms rather than general statements whose precise implementation may be questionable by definition.

A direction in which a more specified and more operational view can be sought is to go back to the conceptualization of complexity proposed above. This conceptualization includes the interaction of an agent or subject (observer, investigator, operator) with a subject matter or object. Indeed it involves three distinct things viz. the observer's behavior, for short, the observed subject matter, and their interaction. The behavioral focus on observer's behavior leaves open a space for exploring whether a more thorough specification can be obtained on the side of the other two terms. It is our contention that a positive response can be brought through the exploitation of John von Neumann's and Heinz von Foerster's contributions to complexity thinking.

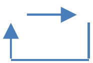
Von Neumann relates complexity to the observed subject matter side. In his theory of self-reproducing automata, he evokes complexity, not distinguished from complication, succinctly but in an insightful way. He connects complexity with a process/product pair used to describe the working of a machine or automaton, something that produces something. Complexity denotes an outcome or product whose "complexity" (indeed, intricacy) exceeds the intricacy of the process which produces it beyond a threshold. Below it, what is produced is less complex than what produces it. In von Neumann's own terms "There is (…) this completely decisive property of complexity that there exists a critical size below which the process of synthesis is degenerative" in the sense that "every automaton that can produce other automata will only be able to produce less complicated ones" (von Neumann, 1961: 318), "but above which the phenomenon of synthesis, if properly arranged, can become explosive" (von Neumann, 1966: 80).

In his work on observing systems, and more generally on second-order cybernetics or "the cybernetics of cybernetics", von Foerster emphasizes the interaction subject/object or observer/observed out of which complexity arises (von Foerster, 2003). In this interaction, the observer is part of the system. Self-referentiality and recursiveness ensue from it. Recursiveness is a particular circular relationship between two terms in which the thing that is produced affects the thing that produces it. It can be transposed to the behavioral search process. As long as the search process unfolds and the intractability of the problem-situation holds, the process of mutual adjustment between ends and means as depicted above is recursive. Active recursiveness stops when satisficing, or tractability, is durably obtained.

It seems manifest at this point that these separate insights complement each other and can be thought of to form a combination. This combination of the Simonian search process with the Neumannian process/product pair, and with the Foersterian recursiveness suggests forcefully to view intractable complexity through a recursive interaction between a generative mechanism (GM) and its product (P) in a heuristic behavioral search process.

We symbolize this recursive duality by a recursive loop between GM and P: GM  P

The square angles are meant to signal that "not anything goes" and that it is subject to declared in advance criteria of scientific practice.

A simpler symbolization is: (GM ∗ P) with ∗ = 

The star symbol (∗) is to be read as the process leading recursively to each one of both terms, from GM to P and from P to GM, which describes an elementary recursive cycle. A learning or search process is intrinsic to this formulation. It involves successive cycles which are therefore, of necessity, indexed over time. GM and P may themselves evolve as learning proceeds via several steps of iteration until a satisficing P is obtained. This recursive duality is generic, it forms the building block of intractable complexity.

3.5 A recursive search process

3.5.1 Nested recursiveness

The building block of intractable complexity consists in a specific recursive duality. It is not between any two terms in a process-product pair, but between a generative mechanism and its product and is therefore also a generative duality. This has several important implications.

There is first what may be called *conjunction*. It introduces a "both…and" way of thinking in place of an exclusive "either…or" dichotomy. Then intractable complexity is neither a property of P, of an object of thinking or of inquiry taken separately from GM, nor of GM taken also separately from P, but a property of both, of their interaction. In the same vein, intractable complexity is neither objectivist nor subjectivist, neither ontological nor epistemological, but it arises out of a process of construction of knowledge in which it can be viewed as a property of both, of the very duality of terms. These terms are not in a mutual opposition but they complement each other, though in an essential tension. The ontology/epistemology dichotomy surfaces again here. Ontology focuses on the nature of reality, while epistemology deals with how we gain knowledge of reality. This apparent opposition masks a circularity noticed by D.T.Campbell and A.H. Van de Ven: "Ontology has to do with what exists, independently or whether or not we know it. But to describe what exists I have to use a language of knowledge claims, and hence contaminate the definition with epistemology" (Campbell, 1988, p.40, quoted in Van de Ven, 2013: 38). However this circularity needs to be qualified, it is not simple or static. Complexity is not inherent to reality but to our knowledge of reality, it is derivative rather than inherent. In McIntyre's terms, complexity exists "not merely as a feature of the world, but as a feature of our attempts to understand the world" (McIntyre, 1998: 28). It arises out of our epistemic interaction with the world. However circular it may be, it is expressed by a cognizing entity and is epistemic first. Rather than oppose the ontological and epistemological views, it seems reasonable to consider intractability dynamically. It starts as a limit to our knowledge of the world and proceeds further through our engaging in interaction with the world. A corollary is that the building block works both as a representation *of* some intractable problem situation and as a tool *for* coping with it. It combines in an essential way a property of an observed object or subject matter and of a process of search.

Second, the building block denotes an *open ended* or *flexible duality*. Whether or not intractability exists in a problem situation depends on a plurality of factors as Table 3 illustrates. The reflective cognitive behavioral setting enables to introduce a dividing line which manifests itself in a flexibility of (GM ∗ P) in the sense that it works as well for intractability as for tractability. If a problem is tractable, it means that a solution P is brought through the use of GM, and the problem stops at this point. There is no need to iterate additionally from P to GM and then again to P, as it is the case when P is not satisficing. A problem can be tractable and later on be intractable, and again tractable, etc., in function of the elements of situation recognition. Recursiveness can be activated and deactivated in turn.

A third implication is *fluidity* and *imbrication*. This model *of* intractable complexity is simultaneously a model *for* coping with intractable complex phenomena in social science. To make clear how this property arises, we need to introduce an additional distinction between meta and object logical levels. The observer is always at a meta level comparatively to the object of observation, at the object-level. The observer acts indeed as a GM generating an observation P of a subject matter standing at the object-level. In an empirical problem-first perspective, the starting point belongs to the object-level. If a problem appears intractable, recursiveness invites to view it as the product P of a generative mechanism which are both at the object-level, and indexed with o: $\mathrm{GM}o * \mathrm{P}o$.

The observer's task is to supply an explanation for it. This explanation takes place at the meta level m. It is itself a P*m* generated by a GM*m*. If the situation is intractable, it means that P*m* is not satisficing. Then there is no other way of avoiding being blocked at this level than inquiring self-referentially by considering the *m* situation as itself the product of a process at a still "higher" level, or meta-meta-level (*mm*) relatively to the meta-level. This is precisely what is done here in searching for a *mm* model that would likely generate a satisficing or less intractable situation at *m* for dealing with the empirical, object level case studies which triggered this research. This recursive inquiry involves a chain of the duality whose recursive structure repeats itself throughout these three levels but with different meanings depending on each particular level, which confers it a kind of self-similar appearance. It amounts to a three level, hierarchized, and nested chain of the generic recursive duality with a fluidity of recursiveness inside and across levels, and constrained by scientific practice. This chain of nested recursiveness can be symbolized as:

$$(\mathrm{GM}mm * \mathrm{P}mm) * (\mathrm{GM}m * \mathrm{P}m) * (\mathrm{GM}o * \mathrm{P}o) \quad \text{or:} \quad (\mathrm{GM} * \mathrm{P})mm * m * o$$

It is a two way imbrication. In the "descending" way, the product P at one level leads to the GM at the immediately lower level: P*mm* leads to GM*m*, P*m* leads to GM*o*. In the "ascending" way, the generating mechanism GM calls for a P at the immediately upper level: GM*o* calls for a P*m*, GM*m* calls for a P*mm*.

3.5.2 An abductive modus operandi

The modus operandi starts with the empirical phenomenon P*o* and with asking how it is generated, which amounts to ask what its GM*o* consists of, and how this GM*o* leads to P*o*. It is wholly abductive. *Abduction* is a mode of inference in which a phenomenon is explained by assuming and identifying a mechanism which is capable of producing it. In sum, to generate is to explain. This type of inference is especially suited to phenomena that are singular, for which induction makes no sense, and which can hardly be tackled through deduction, the inference to a conclusion from a finite sequence of axioms or premises that are held to be true.

Situation recognition, depicted in Table 3, follows immediately. If a satisficing response to the initial question is brought, then the problem is tractable and the search stops at this point. If no satisficing answer can be obtained, then the nested recursion expressed above operates.

The next step is counterintuitive. It is *complexification*. It runs against the spontaneous temptation to simplify it when a problem resists our efforts to control it. The failure to obtain a satisficing P*m* for GM*o* means the failure to obtain a satisficing GM*m* leading to P*m*, at the meta-level. A reasonable, abductive hypothesis to explain this failure is that i. some unknown relevant factors are not captured; ii. to capture them, or some of them, the scope of inquiry must be broadened before one may envisage to produce a satisficing GM*m*. This bottom-up move leads necessarily to the meta-meta level.

It is followed by a top-down move from the meta-meta level to the meta level and finally the object-level. It starts with *reduction*, through the abductive selection of factors which may contribute to generate a GM*m* and ultimately a GM*o*. An intermediary crucial step is to devise a meta-model GM*m* leading to P*m*.

The final step in this looped process is the testing of the validity of the GM*o* thus obtained. There seems to exist no better way than to *implement* and experience it pragmatically. If this cannot be readily done for reasons of size and of the too large amount of the resources that would be needed, a requirement is that at any rate, it should be stated in terms enabling the public checking of the whole procedure and its possible actionability. Actionable knowledge denotes any knowledge involving a specification of the actions that must be taken to achieve the intended consequences (Argyris, 1996). If it still proves to be not satisficing, then a next iteration is called for.

3.5.3 Applications

Road safety

The road safety case (Delorme, Lassarre, op. cit.) can be used as an exemplary illustration of the search process described above although it was conducted in a quite different context of research, in which the main issue was not to theorize complexity with nontrivial phenomenal intractability but to come to grips with a problematic empirical phenomenon. However the research that was developed there can be reformulated in terms of successive steps ranging from situation recognition to abduction, to complexification, to reduction, and to implementation.

Situation recognition starts with the gap in mortality rates and its unexplained long lasting and quasi constant character. It is "explained" quantitatively through the structural decomposition of quantifiable risk factors but remains unaffected by the measures taken to curb down these factors. However, the measures that have been taken year after year for more than fifty years in both countries, though effective in absolute terms in each country, have so far had no effect on the gap itself. Some unseen and unquantified factor(s) must be operating underneath or beyond what is observed quantitatively. Yet, there exist qualitative analyses but it was found that none of them addresses the issue at stake here. None of them is integrated in a unified research combining quantitative and qualitative features.

Complexification is conducted through broadening the scope of study to road safety as an activity, rather than keeping it circumscribed to statistical data concerning risk factors. The rationale was to situate road mortality within a broader setting more susceptible to encapsulate a larger array of risk factors, those relating notably to behavior shaping mechanisms (organization, immediate and mediate contexts of driving, riding and walking by road users). It ended up with information covering eleven fields of road safety activity and a grouping of road safety actors in several broad categories. Complexification manifests itself at the meta-meta level.

Reduction starts at the meta-level with an abductive hypothesis consisting in the representation of road safety activity in both countries as road risk regulation regimes or R4s. Their comparison revealed three differentiating factors, namely professionalization, integration, and evaluation. It is their combined and complementary interaction as a unified factor that seems to be at the source of the long lasting gap. This factor, which has a positive influence on safety performance, operates durably at different levels in the two countries, higher in Britain, lower in France. It provides the generative mechanism, at the object-level, leading plausibly to the gap.

Regarding implementation, this result is stated in actionable terms. It awaits implementation in France, in a context in which institutional and organizational inertia are not absent. All in all, it illustrates a case in which the tractability of an initially intractable problem can be achieved, at least in principle.

State-economy interactions

The Franco-German case offers a quite different picture. It is much more multidimensional and intricate than road safety activity and governance. The step by step procedure that was followed for the safety gap is out of reach here. Whereas the aspiration level is clear cut with road safety, no such a thing occurs for the aspiration level that is attached to an underpinning theory of state-economy interactions. Where should an adequate theory stand, in between a grand theory and pragmatically devised orientations and guidelines for economic policy making? It is clear that this research supports the latter. It does so in full awareness of the possible presence of intractability, which implies the need of situation recognition, and the need to beware of doctrinal and theoretical constructs established in the neglect of the possibility of intractability.

The next question is where to place the cursor. The answer depends on the aspiration level and the resources that are available. A reasonable aspiration seems to produce sensible knowledge, not in substantive terms from the start but in terms of the process leading to a substantive outcome, which implies recognizing the situation and establishing a dividing line first.

A theory one may envisage is then a theory fully based on intractability and being open ended, making room for conventional analysis when it turns out to be tractable with the conventional toolkit. It introduces a new way in theoretical discussion and imposes a limit to hubris. Several lessons follow from it. First, whenever intractability is present, it is not appropriate to rely on P first, on substantial modelling and advice. It is more appropriate to rely on GM, on process first, at both the meta and the object levels. It leads to a notion of procedural or generative modelling. Second, it seems appropriate to act as if intractability were present from the start since it is the only way to recognize the problem situation and to act accordingly. Intractability does not lead to paralysis but to constructive action through explicit deliberative discussion among informed stakeholders. This is all the more necessary when values and economic analyses are in conflict and prevent from aspiring to a "one best" substantive model. A final lesson is to manage to have some flexibility for implementation, for experiencing, and for iteration if necessary. All in all, an appropriate theory for the state-economy interactions cannot be on P first but on the very recursive process $GM * P$ itself. In the present research it takes the form of a regime of interaction between the state and the economy or RISE. In this setting, it is within a given RISE that a substantive analysis leading possibly to specific policy orientations can be pursued.

J.M. Keynes's methodological revolution

The challenge with Keynes's oeuvre is that his theoretical revolution has been the main focus of attention and of controversy for decades in economics whereas its methodological background has been broadly overlooked and even downgraded. Accusations of inconsistency followed from it. A reason for this situation is that Keynes never exposed thoroughly his method. Statements on his method by him are partial and scattered. Several contributions in the 1980's and the 1990's attempted to remedy this situation (Delorme, 2013). It is our contention that the model of intractable complexity adds to this debate by helping to make sense of Keynes's revolutionary methodological insights, and of their limits.

On the first account, Keynes appears as a precursor who attempted to adapt in his own way his thinking to what he perceived as the complexity of the subject matter of economics. Although he did not refer explicitly to the term "intractability", the consequences of intractability pervade in several fundamental principles that can also be found in our modelling. These principles include a priority to realities of the world ("problem first" here) rather than a priority to the formal, analytical capacity of treatment, a priority to organic interdependence (intricacy here) and uncertainty rather than to atomicity and risk, a priority to ordinary logic and language rather than to formal logic and language, a priority to non-dualism and open-endedness ("both…and" here) rather than to either…or exclusive dualism. One may even detect two levels of method, an encompassing and overarching one resulting from the combination of the principles enumerated above, and "particular" methods adapted to the issues at hand, a distinction which fits with the meta level overarching method proposed here as a constraining and enabling frame for particular procedures at the object-level. In hindsight, Keynes's thinking integrates methodological orientations that follow from the intractability of the phenomena he addressed.

The big problem with this way of thinking is about the dividing line with conventional analysis, and about the mechanism for dealing with issues not captured adequately by conventional analysis. They necessitate a framework enabling to establish the coherence of hypotheses and notions that remain scattered in Keynes's work. Keynes's eclecticism lacks the specification of a unifying and integrative framework.

4. Concept attainment

The modelling developed above may appear unsettling although it is constructed on the basis of an explicit frame of reference. Yet its dual character of being both a model *of* intractable phenomena, and a model *for* dealing with them, is disturbing and needs clarification. How can we make sense of it? And what kind of bearing can it possess beyond the case studies that triggered an interest for it? How can the heuristic process of which it is the outcome be characterized in a more unified and condensed way, thus enabling to make of it an operational concept and tool for research?

According to its dictionary definition, a concept is an abstract or generic idea generalized from particular instances, which enables one to think of a diversity of cases in a unified way. Therefore, answering the questions raised above necessitates first to put the pieces together. To do it, we pursue with an abductive style of argumentation. Under this view there arises the idea of a focus on process or procedure prior to final substance. However this notion of a *procedural* modelling is quite general and does not convey the particular characteristics that needed to be elaborated in order to achieve an effective capacity to cope with specific concrete issues. The concept that we are attempting to formulate must be operational and facilitate effective research rather than staying confined to mere conceptual and abstract discussion. In this vein there does not arise an immediately identifiable prevailing characteristic. It is rather the idea of a combination of various elements making up a unified modelling process that imposes itself to the mind. We contend that this modelling stands on the combination of three principles whose nature is explained below. Naming this combination will be our final response to the task of concept attainment.

4.1 First principle: Reflexivity

We have moved in the developments above from an initial awareness of nontrivial phenomenal intractability to a frame reflective cognitive approach which, in turn, led to a process in which the modelling *for* coping with intractability arose as being simultaneously a modelling *of* the intractable phenomena under study. This process is reflexive, but in a specific way, from which follows the need to clarify the meaning of "reflexivity". In its dictionary definition of that which is "directed back on itself", reflexivity has different meanings in different contexts and can occur in a plurality of human activities (Hands, 2013).

In our research context, three different meanings are present. One pertains to reflexivity as a relation always holding between a term and itself. In this sense, the nested recursive process depicted in 3.5.1 is reflexive: it is a relation between $*$ and itself. In a second meaning, reflexivity denotes a continuous process of reflection on the conditions of knowledge construction. Both meanings operate in the reflexivity at work here. This reflexivity combines them in a way that can be summarized as follows.

It involves a two way relationship between (GM $*$ P) and itself, or between $*$ and $*$. This relationship operates on the one hand from object-level $*$ to meta level $*$ (or from subject matter to observer), and on the other hand from meta level $*$ to object-level $*$ (or from observer to subject matter). Therefore it combines two sequences. One is the initial, empirically triggered sequence from object-level to meta level, the other one is epistemic and metacognitive from meta level to object-level. The former focuses on the "what", the modelling "of" the particular subject matter whereas the latter focuses on the "how", the modelling "for" dealing with this subject matter. Both rely on the same recursive building block and make up one and the same reflexive modelling process. Meta and object refer to any pair of successive logical levels in a chain that can range from the initial empirical object-level to the meta and meta-meta levels, and vice versa, as was illustrated in the road safety case. Reflexivity, the repeated application of (GM $*$ P) to itself, operates at all logical levels. It encapsulates the plurality of elements that were introduced both in problem formulation and problem solving.

At this point, there arises the question of the possible affinity of the reflexivity in operation here with George Soros's theory of reflexivity (Soros, 2013). Although space does not allow to fully compare them, a clarification is necessary. Soros's view relates to a third meaning of reflexivity, that is, a situation in which the participants' views can influence the situation to which they relate through their interactions which in turn will change the situation, which will in turn change the participants' views, etc.: "the participants' thinking is part of the reality that they have to think about, which makes the relationship circular" (ibid.: 310). In Soros's analysis, reflexivity of the social or economic world results from a combination of fallibility, of radical or "Knightian" uncertainty (ibid.: 328), and of complexity. Fallibility denotes situations in which "the participants' views of the world never perfectly correspond to the actual state of affairs (…) and are bound to be either biased or inconsistent or both" (ibid.: 310). Complexity pertains to "the world in which we live", which "exceeds one capacity to comprehend it" (ibid.: 311). Soros is dealing here with notions of complexity and reflexivity following from limits to knowledge, and he even comes close to intractability with the idea that complexity denotes a situation which "exceeds our capacity to comprehend it". This view on complexity is complemented in a work of clarification of Soros's ideas (Beinhocker, 2013) in which the complexity "of the system in which the agent is embedded" is defined as resulting from "multiple interactions between agents" and "nonlinearity in feedbacks in the system" (ibid.: 332) which amounts to equating complexity with intricacy. The irony is that it is the combination of these two partial views that makes up the complexity envisaged in this paper. Yet, this reconstituted resemblance goes with a fundamental difference.

Soros's reflexivity is ontological. It is a property of financial markets (Soros, ibid.: 311, 321) that is extended to "social sciences in general" and "economics in particular" (ibid.: 310), and to "economies" as "reflexive systems" (Beinhocker, ibid.: 339). The reflexivity envisaged in the present paper gives priority to epistemic considerations for addressing "real world" issues stemming from significant empirically experienced facts. It is the reflexivity of the modelling itself, in the two meanings introduced above, rather than the reflexivity of a social system or of "economies" considered as reflexive systems. Whether the empirical substance of the problem, rather than "the system" or "the economy", is better viewed as being reflexive or not depends on the problem at stake, and is handled through the metacognitive and encompassing character of the modelling, both at the meta- and the object-levels. Here, reflexivity follows from intractability. But this intractability is not an a priori, presupposed ontological feature of the "real world". It results from a cognitive behavioral procedure of situation recognition. In case the problem is found tractable with the existing conventional toolkit, there is no need for other tools.

All in all, our argument may be summed up as the reflexivity of a recursive and generative cognitive behavioral modelling. Reflexivity enables to think of $*$ not only in terms of a meta loop but also in terms of an object-level loop whatever the size of the object-level subject matter is. Therefore, this modelling approach is not limited to micro-phenomena and decision-making, it applies as well to large size and macro-level issues.

4.2 Second principle: Centrality of the complexification-and-reduction process

The cognitive behavior which supports this modelling involves a search process in which complexification comes first. It is counterintuitive. In its emphasis on complexifying first rather than first reducing or simplifying the problem situation, it runs against a spontaneous tendency and common wisdom. It does so by contextualizing and enlarging the scope of the problem situation in order to reduce it in an abductive way in the next step, as is best illustrated in the road safety case. Complexification finds an antecedent in James Dewey's transaction, the "conversion of ontological separations into functional distinctions envisaged within a more inclusive whole" (Dewey and Bentley, 1949: 132). But transaction is only one moment in the broader process of complexification. Complexification-first has an important implication for research. It is that the ordering of operations does count. Simplifying out of the not previously complexified is different from simplifying out of the previously complexified. They are not commutative. In the face of nontrivial intractability, it is the latter that augments the chances of capturing significant generative features of a phenomenon that would be left aside in most cases by spontaneous, direct simplification.

4.3 Third principle: Non-commutative complementarity

The second principle has an important implication for research in social science. It pertains to the distinction between procedural and substantive modelling, and to their respective connections with complexification and simplification. Substantive theory bears on the substance or product thus differentiated from the procedure or process leading to it or generating it. According to the cognitive behavioral setting, it is appropriate when it is the outcome of a process of deliberation or when the situation is simple and transparent enough so as to dispense from a procedural deliberation, and to warrant a direct "rationally" substantive outcome. Procedural and substantive modelling are therefore complementary. But it is a non-commutative complementarity in which procedural modelling comes first, for reasons that are similar to the centrality of the complexification-first search process. In this way, complexification closely connects with procedural modelling. It confers an encompassing and subsuming character to procedural modelling. And the cognitive behavioral framework strengthens the case for generality since what is crucial is the problem situation created by the interaction of an operator and a subject matter, not the particular discipline or object of study. Such a problem situation refers to cognitive behavior in a given context independently of any disciplinary dependence. Therefore the cognitive behavioral procedure modelled above is not limited to cases of complexity with nontrivial phenomenal intractability. It extends to any cognitive behavior in scientific practice in social science and operates as a metacognitive sorting mechanism.

This non-commutative complementarity of procedural modelling with substantive modelling goes against the belief in the "oil spot dynamic" (Fontana, 2010) of extending the standard substantive perspective to ever more complicated problems, thereby making procedural modelling unnecessary. There is a qualitative discrepancy between the two perspectives: the a priori substantive one excludes any problem calling for a genuine procedural deliberation whereas the procedural one includes as its outcome the possibility of a substantive modelling, as was illustrated in the road safety case. Non-commutative complementarity tells that not every problem is intractable but that in order to identify what is tractable and what is not, and to sort them out, it is necessary to behave from the start as if every problem were possibly intractable and give priority to procedural modelling and complexification.

Incidentally, our argumentation suggests a different dividing line between broadly understood mainstream, and heterodox perspectives in economics. It displaces the borderline through its reliance on a cognitive behavioral basis rather than the greater realism commonly invoked in heterodox circles to justify their own demarcation from general equilibrium and individual optimization that are deemed to be the hallmarks of orthodoxy. However, most heterodox and orthodox approaches are alike in their sharing of a substantive view of theorizing despite the endless and inconclusive debates on the realism of assumptions and outcomes for most of the large size issues that are at stake in political economy. A common trait of substantive theorizing is its focus on the "what", on the classical triplet of prediction - be it event or pattern prediction -, explanation and control, rather than on the "how", in the same vein as Simon observed that "economics has traditionally been concerned with *what* decisions are made rather than with *how* they are made - with substantive rationality rather than procedural rationality"(Simon, 1978, 494, italics in original). In the terms introduced here, substantive modelling denotes a focus on P rather than on both GM and the (GM, P) paired process. Without willing to be provocative, one can hardly help consider that, to the extent that they focus on a substantive view of economic matters, most theoretical heterodox views, including most post-Keynesian theory, travel alongside with orthodoxy, with notable exceptions among which are Keynes and Simon.

The procedural theorizing presented here has no claim at being a grand theory. It proposes a pragmatist and constructive approach grounded in problems as they are socially experienced, and trying to deal with them in an open ended, cognitive behavioral way subject to a reflective scientific practice. Realism or realisticness is in-built since the production of actionable knowledge and theory, and its implementation, are inherent to the search process. There is no claim here that substantive theorizing is wrong, only that it is problematic when there is no explicit procedural justification of it, especially when the possibility of intractability cannot be assumed away from the outset. This very possibility of intractability has therefore non negligible consequences for theorizing in fields such as social sciences in general, and economics in particular, in which one cannot rely on the tools which enable to cope with intractability in the hard sciences (Lévy-Leblond, 1991).

4.4 Naming it

It is the combination of these three principles that makes up a procedural cognitive behavioral modelling. It enables to cope with intractable complex phenomenal issues in social science and it provides a mechanism for sorting these problems from those that can be addressed conventionally. At this stage, it will help to express in a single phrase the concept of a modelling that is at once complex, reflexive and procedurally non-commutative. It encapsulates *both* a property of a situation, that is, complexity with nontrivial phenomenal intractability, or a deep complexity, *and* the process leading to it, or a generative procedure. Therefore the phrase "Deep Complexity Procedure" - or Deep Complexity, in brief - seems appropriate for this concept.

5. Concluding remarks

It has been asserted elsewhere that "complexity economics" provides "a different framework for economic thought" in its attempt to resolve problems by appeal to computer simulation (Arthur, 2015). Notwithstanding how much valuable complexity economics may be, this paper has claimed that there exist significant problems in economics in particular, and in social science generally, that are not resolved by computer simulation. Deep Complexity addresses those problems that remain immune to resolution by appeal to computer simulation. It offers an encompassing and procedural basis for substantive modelling in economics and social science. It is both a theory *of* complex intractable phenomena and *for* coping with them.

Deep Complexity suggests how social science theorizing might be more effective by taking phenomenal intractability more seriously. Unsurprisingly, this runs against profoundly ingrained beliefs and prejudices about good science in social science. One may then wonder what kind of science is a science that is unable to admit its own cognitive or epistemic limitations. Such a science is deprived of the means that would provide it with an incentive towards a more responsible, less hubristic practice. May further research coping with intractable phenomena provide exemplars and encourage taking phenomenal intractability more seriously in economics and social science.

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Table 1 Six approaches to complexity in social science

Approaches to complexity	Domains of application	Main focus or goal	Status of intractability	Contribution to this research	Pending issue
Dynamic	● Computer simulation of behavior of complex systems ●Evolutionary complex systems	●Understanding the behavior of complex evolving systems	●Trivialized	● Out- of-equilibrium reasoning ● Focus on generative processes ● New way of doing science	● Problematic connection with concrete phenomena ●No explicit concern for intractability
Computational	● Theoretical and practical limits to computation	●To compute solutions	● ***Not trivialized***	● Scientific legitimacy of the study of nontrivial intractability	● Effective computability ● Dividing line between tractability and intractability
Conceptual T	● Systems thinking ●Philosophical complexity thinking	● Alternative to analytical reductionism	●Trivialized	● Non-reductionist ●Complexity as an epistemic matter	● No concern for intractability
Conceptual NT	●Philosophical limits to knowledge ●Second-order cybernetics	● Critical reflection on limits of knowledge	● ***Not trivialized***	● Support for not giving up when intractability ●Support from s-o cybernetics for constructive self-reflexive reasoning	● Distant from theoretical and empirical problem-solving, and programmatic
Phenomenal T	● Systems approach to empirical issues	● Empirical problem solving	●Trivialized	● Non-reductionist way of doing science	●Intractability not discussed or neglected
Phenomenal NT *(Detailed in Table 2)*	● Plurality of areas	● Empirical problem solving	● ***Not trivialized***	● Support for inquiry-driven and heuristic search	● Case specific ● Lack of a modelling of nontrivial phenomenal intractability

Symbols: T= trivial
NT= nontrivial

Table 2 Instances of nontrivial phenomenal intractability in social science

Author	Research area	Origin of intractability	Response delivered
H. Simon (1976)	● Decision making and problem solving	● Problem-situations in which substantive rationality is not appropriate	● Procedural rationality
J.M. Keynes (1936)	● Macroeconomics	● Organic interdependence of the economic material and radical uncertainty	● A methodological revolution
E. Ostrom (2010)	● Political economy, community-based governance of common pool resources	● Study of subject matter irreducible to one single method	● Methodological pluralism
D. Schon & M. Rein (1994)	● Public policy controversies	● Multiple, sometimes incommensurable evaluative perspectives	● Frame reflection
O. Barreteau & al. (2010)	● Management of renewable resources and the environment	● No one single general theory of model validation	● Companion Modelling
S. Funtowicz & J. Ravetz (1999)	● Management of complex science-related issues, notably environmental and ecological	● Cases where "facts are uncertain, values in dispute, stakes high and decisions urgent"	● Post-Normal Science
P. Checkland (1999)	● Management of organizations	● Hard systems methodology inadequate to "real world" problem situations	● Soft Systems Methodology
R. Stacey (2000)	● Management of organizations	● Situations of high disagreement and uncertainty	● Stacey Matrix and co-responsive processes of interaction
A. Van de Ven (2013)	● Organizational and social research	●"Complex social problems that often exceed our limited capabilities to study on our own"	● Engaged Scholarship
C. Perrow (1999)	● Safety science	● Unresolved difficulty of fully preventing big accidents in high-risk technologies	● Normal Accidents
R. Delorme (2010)	● Political economy ● Safety science	● Unresolved difficulty of dealing with particular complex phenomena in empirical research	● Deep Complexity

Table 3 A conceptualization of complexity

Complexity	Intricacy or problem of computation	Difficulty of solving it in theory	Difficulty of solving or resolving it in practice
Dynamic	● High-level intricacy	● As if solved	● As if tractable
Computational	● Computation problem	● Computable in polynomial time	● Tractable except for certain large instances
		● Computable in more than polynomial time	● Intractable except for certain small instances
		● Uncomputable	● Intractable
Conceptual	● High-level intricacy	● As if solved	● As if tractable
		● Not solved	● Intractable in principle
Phenomenal	● Low to average-level intricacy	● Solved	● Tractable
	● High-level intricacy	● Not solved	● Intractable in principle

Table 4 A cognitive behavioral situation recognition

	Case study on public spending	**Case study on road safety**
1- Subject matter	● Regime of interaction between the state and the economy	● Gap in road safety at country level
2- Purpose	● Theorizing	● Lowering the gap
3- Operator	● Economist	● Safety analyst
4- Field of activity	● Economic analysis	● Governance of road safety at country level
5- Aspiration level	● An underpinning theory	● An effective procedure
6- Level of intricacy	● Very high	● High
7- Substantive tractability	● No	● No
8- Procedural tractability	● No	● No
9- Judgment of intractability	● Trivialized or not trivialized	● Trivialized or not trivialized
10- Character of situation	● Complex or complex-with-nontrivialized-intractability if intractability not trivialized	● Complex or complex-with-nontrivialized intractability if intractability not trivialized