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Edgardo Bucciarelli
Marcello Silvestri
Sara Rodríguez González *Editors*

Decision Economics, In Commemoration of the Birth Centennial of Herbert A. Simon 1916-2016 (Nobel Prize in Economics 1978)

Distributed Computing and Artificial Intelligence, 13th International Conference

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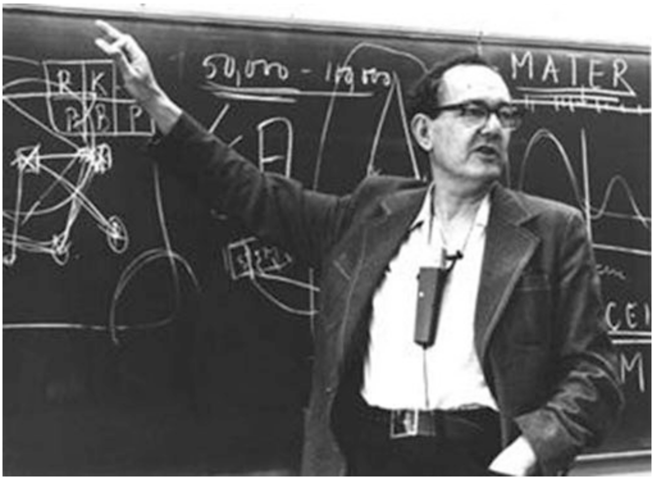
Preface

"There can no longer be any doubt that the microassumptions of the theory - the assumptions of perfect rationality - are contrary to fact. It is not a question of approximation; they do not even remotely describe the processes that human beings use for making decisions in complex situations." (Herbert A. Simon, from the Nobel Lecture, 1978, p. 366)



Decision economics, in commemoration of the Birth Centennial of Herbert A. Simon 1916–2016.

This book presents a selection of distinguished contributions to the research field of economics and decision-making presented at the special session on "Decision Economics" during the 13th International Conference on Distributed Computing and Artificial Intelligence (DCAI) 2016 held in the University of Seville, Spain.

There was a special reason for holding this session during the Conference: the commemoration of the Birth Centennial of Herbert A. Simon, 1916–2016, one of the pioneers and founders of Artificial Intelligence (AI) and the main precursor of the modern Behavioral Economics (BE) with the related applied research that has resulted in order to progress economics. The special session provided an international forum for social scientists to discuss emerging topics and integrate insights from basic research with those stemming from more applied research efforts. The extensive research done in the emergent field of *decision economics* has raised fundamental questions and issues regarding the nature of rationality. These questions and issues particularly affect the decision theory, which is a crossroads of different scientific disciplines – statistics, mathematics, probability calculus, psychology, biology, economics, and philosophy – around which numerous efforts have been made to compose or recompose a single behavioral model to be valid for several applications. Nevertheless, decision theory is concerned with goal-directed behavior in the presence of alternatives (options). Therefore, decision theory can in turn be placed in the wider field of behavioral studies by finding its most innovative definition within the complex of cognitive sciences.

The first appearance of interest in the cognitive sciences and their contribution to the interpretation of economic phenomena is traced to Herbert A. Simon. The scientific community has unanimously recognized the fundamental role played by Simon's insights in this context and the upheavals generated by him in the concepts and methods of microeconomics and applied economics. His theoretical and methodological reflections proposed a veritable paradigm shift with respect to the views grounded in neoclassical economics. Specifically, among others, Simon argues that economics should not deal of rational behavior in an abstract manner, but must re-found itself as an empirical study of the limitations of the decision makers' capabilities and how those limitations affect the actual economic behavior.

Not yet thirty, Simon was the first to discuss the issue of decisions made by managers within business organizations, when those decisions are made under conditions of uncertainty, that is, when the available information is imperfect because inaccurate and incomplete. Although these decisions basically aim at maximizing profits, it is not evident from an empirical standpoint that entrepreneurs, thus in general business organizations, necessarily follow the principles of the marginalist tradition of maximizing profits and minimizing costs. This is due, in large part, to the inherent limitations of rationality rooted in the decision-makers. Because of these limitations, decision-makers can only make decisions not aiming the optimum, i.e. the absolutely best decision of all possible decisions, but settling for the *satisficing*, that is an acceptable decision. Hence, the objective of business organizations is not addressing issues related to the optimization, such as maximizing profits, but finding acceptable solutions to urgent problems. In particular, Simon proposes, as the best method to study problems of this nature, the modeling with computer simulations according to AI and BE methods. Last but not least, from the origins in the classic works of Herbert Simon, the two subjects of AI and BE appear to have developed into several sub-fields, all of them actively pursued at the frontiers of economic theory and applied economics.

On the one hand, therefore, for a long time the economic analysis considered decisions whose consequences are supposed perfectly foreseen and, therefore, perfectly planned. This is the case of the consumption and production theories as well as the theory of market structures and the related industrial organization approach. Over the past sixty years, however, the field of analysis was extended to include also the decisions under risk and uncertainty. In developing this analysis, the standard economic theory had to rely on both drastic and unrealistic simplifications, and on the predominance of strongly reductionist research programs characterized by a deductive logic. On the other hand, the current research is engaged in an effort to reverse the trend, in the hope of reaching a more accurate and truthful description of reality based on observations and experimentations, becoming able to explain those actual phenomena shortly considered or completely neglected by the mainstream economics. In Herbert Simon's vision, economics shares a common ground with the traditional sciences of nature, but concurrently benefits from the fact of being addressed as engineering sciences. The economic science, in fact, as the natural sciences investigates reality starting from the need to observe real phenomena and, as the engineering, aims to build processes and artifacts that meet the purpose for which they were conceived by humans, since they put in place projects for human action, well-being and happiness.

In a nutshell, *bounded rationality*, *satisficing* and *problem solving*, within the context of decision processes faced by economic agents situated in complex organizations evolving dynamically, in a macro-economy viewed as a complex dynamic system, characterize the subject that has gradually come to be called *decision economics*.

In line with this debate, several contributions are presented in this volume, each of which has gradually moved away from the idea of being able to develop a general theory of decision-making, thus leaving open the question to see to what extent the results achieved analytically can then be translated, given different actual forms of rationality, in a real progress to understand complex phenomena. Therefore, this book discusses decision economics from a wide spectrum of methodological issues and applications. The content of each chapter is discussed next.

Chapter 1. *"The missing legacy of Herbert Simon in Agent-based Computational Economics"* by Shu-Heng Chen. In this chapter, the author provides insight into his vision regarding the missing legagy of Herbert A. Simon in Agent-based Computational Economics community. In particular, the author focuses the discussion on two key elements that have been neglected: near decomposability and modularity. The former refers to a system having the so called near decomposible architecture organized as a layers of parts where interactions are much more than those belonging to different parts. The latter refers on how to model autonomous agents capable of discovering chances and novelties without supervision.

Chapter 2. *"Incomplete soft sets: new solutions for decision making problems?"* by José Carlos R. Alcantud, and Gustavo Santos-García. In this chapter, the authors introduce a novel approach for soft based decision making under incomplete information by revisiting a previous work of their own. More in depth, their solution relies on a classical Laplacian argument from probability theory. In view of the computational characteristics of such algorithm, they propose two related solutions that efficiently evaluate problems with many more incomplete data.

Chapter 3. *"A mixed model of optimal saving"* by Irina Georgescu, Adolfo Cristóbal-Campoamor, and Ana María Lucia Casademunt. In this chapter, the authors propose a mixed model to study a consumer's optimal saving in the presence of two types of risk: income risk and background risk. In their model, the income risk is represented by a fuzzy number and the background risk by a random variable. Three notions of precautionary saving are defined as indicators of the extra saving induced by the income and the background risk on the consumer's optimal choice. The authors demonstrate necessary and sufficient conditions for precautionary saving when adopting a mixed model of optimal saving.

Chapter 4. *"The role of technological changes in foreign-exchange market inefficiency"* by Svitlana Galeshchuk. In this chapter, the author develops an empirical methodology to study market inefficiency, which comes from rapidly developing software and technological progress, by introducing a technological bias in the exchange-rate market. The key idea is that computational methods based on evolving software, such as deep neural network, could help to forecast price movements and find the best trading strategies, rather than those methods based on traditional technical analysis.

Chapter 5. *"Web browser-based forecasting of economic time-series"* by V.M. Rivas, E. Parras-Gutíerrez, JJ Merelo, M.G. Arenas, and P. García-Fernández. In this chapter, the authors investigate the role that technology plays in decision analysis by presenting the implementation of a time series forecasting algorithm that uses genetic algorithm written in JavaScript and neural nets. The methodology is based on the use of web browsers as agents able to download a set of data, execute an evolutionary algorithm that evolves neural nets, and apply this neural nets to forecast an economic time-series. The experiments show the results yielded by the algorithm over a data set related to currencies exchange.

Chapter 6. *"Cross-entropy based ensemble classifiers"* by Giovanni Lafratta. In this chapter, the author simultaneously identifies multiple classification rules by applying the Cross-Entropy method to the maximization of accuracy measures in a supervised learning context. The author searches for optimal ensembles of rules through stochastic traversals of the rule space. Each rule contributes to classify a given instance when the observed attribute values belong to specific subsets of the corresponding attribute domains. Classifications of the various rules are combined applying majority voting schemes. The performance of the proposed algorithm has been tested on some data sets from the UCI repository.

Chapter 7. *"How does fairness relate to economic decision-making? An experimental investigation of pro-social behavior"* by Edgardo Bucciarelli, and Tony E. Persico. In this chapter, the authors discuss the role of fairness in economic decisions focusing on Amartya K. Sen's concept of meta-ranking to study sets of preference orderings according to some fair principle. On the one hand, the authors propose a model based on a meta-utility function to explore different structures of preferences. On the other hand, they run an experimental economic game to test the role of meta-ranking, analyzing the results with a tensor-based method.

Chapter 8. *"What network analysis can teach us about Chinese economic structure"* by Vittorio Carlei, Alina Castagna, Leila Chentouf, and Donatella Furia. In this chapter, the authors use a network based approach in order to identify industrial intersectoral interdependencies in the Chinese economy. The idea behind the work is to highlight the behaviour of these interdependencies in reaction to exogeneous shocks or in spreading shocks through the system.

Chapter 9. *"Regional income differentials in Italy: a MARS analysis"* by Iacopo Odoardi, and Fabrizio Muratore. In this chapter, the authors propose a multivariate adaptive regression splines analysis to investigate regional income difference in Italy and in order to provide an efficient complement to traditional econometric techniques.

Chapter 10. *"Data aware business process models: a framework for the analysis and verification of properties"* by Raffaele Dell'Aversana. In this chapter, the author presents a logic framework that enables the possibility of studying the properties of data-aware business processes, and gives directions for open research challenges in order to develop more efficient and effective organizations.

As with any such undertaking, there are many acknowledgements due, and they do not adequately represent the scope and depth of the support received. This book would not have been possible without financial support from the BISITE research group, University of Salamanca, Spain. Indeed, we began this project while we were at the Department of Economics and Economic History of the University of Salamanca and concluded it while at University of Seville, and their support is gratefully acknowledged.

In terms of the content of this book, we have been deeply influenced by a number of colleagues and friends. First and foremost, our initial interest in this subject arose through conversations and subsequent research with Gianfranco Giulioni. We have continued to learn about *decision economics* and enjoy the interaction with a group of scholars listed below in alphabetical order: José Carlos R. Alcantud, Thierry Burger-Helmchen, Claudia Casadio, Shu-Heng Chen, David C. Colander, Juan Manuel Corchado, S. Barry Cooper, Sameeksha Desai, Fernando De la Pietra, John Duffy, Giuseppe Fontana, Felix Freitag, Frank Heinemann, Herrade Igersheim, Rebeca Jiménez-Rodríguez, Amin M. Khan, Jakob Kapeller, Steve Keen, Alan Kirman, Marc Lavoie, Nadine Levratto, Nicola Mattoscio, Rosemarie Nagel, Giulio Occhini, Lionel Page, Carmen Pagliari, Javier Bajo Pérez, Enrico Rubaltelli, Neri Salvadori, Anwar Shaikh, Sergeja Slapničar, Amartya K. Sen, Pietro Terna, Katsunori Yamada, Kumaraswamy Vela Velupillai, Stefano Zambelli, John Wooders.

Finally, this book would not have the value and meaning it does without the support and interest of young scholars and PhD students who have discussed and commented on early versions of the contributions here included.

June 2016

Edgardo Buciarelli
Marcello Silvestri
Sara Rodríguez González

The Editors

Edgardo Bucciarelli is Aggregate Professor of Economics at University of Chieti-Pescara (Italy), he received a PhD in Economics from this university. His main research interests lie in the area of complexity and market dynamics, experimental and behavioral economics, applied economics, economic methodology, development economics. His main scientific articles appeared, among others, in the Journal of Economic Behavior and Organization, Journal of Post Keynesian Economics, Applied Economics, Rivista di Politica Economica, and other international journals. Several key contributions appeared in chapters of book in Physica-Verlag, and Springer Lecture Notes in Economics and Mathematical Systems. At present, he teaches Experimental economics and Economics of financial intermediaries at University of Chieti-Pescara. He is one of the Directors of the Research Centre for Evaluation and Socio-Economic Development and one of the co-founders of the academic spin-off company *“Economics Education Services”*. He is the co-founder, organizing chair, program committee chair in a number of international conferences.

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Contents

The Missing Legacy of Herbert Simon in Agent-Based Computational Economics

Shu-Heng Chen

Abstract In this article, we examine the legacy of Simon in Agent-Based Computational Economics (ACE). We show that both near decomposability and modularity, the two essential ingredients of the Simonian economics, have not been seriously pursued by the ACE community. First, most ACE models are not endogenously multi-level, which makes near decomposability be not much relevant to ACE. Second, while the modularity approach has already been employed by Simon in his artificial intelligence research and can help shape a notion of autonomous agents, this approach is also not well followed by the ACE community. Instead, most artificial agents used in ACE have been put in rather identically repeated environment not much different what the movie "Groundhog Day" depicts [23]. Hence, they are not able to do serious novelty or chance discovery, and the creativity of artificial agents have not been taken seriously by most ACEers.

Keywords Near decomposability · Modularity · Evolving hierarchy · Agent-Based Computational Economics · LISP · Autonomous agents · Multi-level agent-based modeling

1 Motivation and Introduction

In this presentation, we address the intellectual connection between Simon and Agent-Based Computational Economics (ACE). The motivation behind it is that, apart from his invented notion of bounded rationality, Simonian economics seemed to have limited influence on the development of the literature of ACE. Take the only handbook on ACE as an example [22]. There is a total of 22 chapters.

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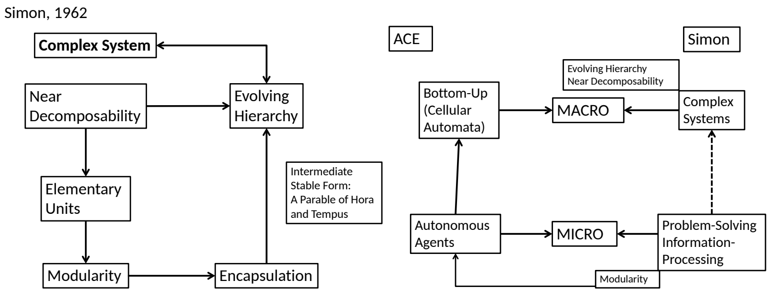

Fig. 1 The Legacy of Simon and ACE

Nine of these 22 altogether cite eight different publications of Simon, ranging from 1955 [17] to 1996 [20], including his books, collections and single articles. Most citations are related to his discussions of *bounded rationality*, including satisficing behavior, rules of thumb, and computational complexity. Apart from bounded rationality, *near decomposability* is the other essential ingredient of Simonian economics mentioned only once by these papers. His contribution on artificial intelligence, specifically those joint works with Allen Newell [15] is not cited, neither is his influential article on the complex system [18].

However, given his pioneering role in artificial intelligence and cognitive psychology, it will be a surprise if the legacy of Simon was largely ignored in ACE, a field in which both AI and cognitive psychology play a crucial role. Therefore, in this paper, we search for the Simonian elements in ACE.[1] The rest of the paper is organized as follows. Section 2 proposes the use of the evolving hierarchy as a general framework in which the relationship between Simonian economics and ACE can be effectively addressed. Sections 3 and 4 review the current state of Simonian economics in ACE in light of its two essential ingredients, namely, modularity and near decomposability, followed by the concluding remarks given in Section 5.

2 A General Framework

In our understanding, the legacy of Simon in ACE can be quite coherently summed up by his work on complex system [18], which is characterized by *evolving (emergent) hierarchies* (Figure 1). Simon did not use the term "emergent", but he did used the term "intermediate stable form" to describe the significance of near decomposability in the (bottom-up) growing process of a hierarchy. In this sense, the larger hierarchy developed later can be considered to emerge from those intermediate stable hierarchies. There are two essential ingredients of evolving hierarchies

[1] In addition to Simon, other Nobel Laureates in economics who have identifiable contributions to ACE include Hayek (1899-1992) [24], Elinor Ostrom (1933-2012) [9] and Thomas Schelling [16].

(Figure 1, Left Panel). The one which was initially proposed by [18] is *near decomposability*, and the other one which is not introduced by Simon but can be derived from his complex system is *modularity*. The modularity element can be found from Simon's classic parable of two watchmakers, Hora and Tempus [18]. Hora knew how to modularize his watchmaking business, while the Tempus did not. As we shall see from the following quotation, in this passage Simon clearly refers to the idea of modularity, rather than the more sophisticated near decomposability.

> The watches that Hora made were no less complex than those of Tempus. But he had designed them so that he could put together *subassemblies* of about ten elements each. Ten of these subassemblies, again, could be put together into a *larger subassembly*; and a system of ten of the latter subassemblies constituted the whole watch. (Ibid, p. 470; Italics added)

The two ingredients are essentially the two sides of the same coin, one from the macroscopic viewpoint (near decomposability) and one from the microscopic viewpoint (modularity) (Figure 1, Right Panel). As we shall see in this paper, they become the two ends of an evolving hierarchical system, from the interactions of individual agents to their emergent aggregates, which nicely fit the general framework of ACE.

To proceed, let us briefly review the evolving hierarchical system proposed by Simon. The evolving hierarchical system is a system which can be recursively decomposed top down or can be recursively integrated bottom up. In each recursion, each system is composed of some subsystems or, alternatively, a set of subsystems are integrated to a larger system. If these constituents are *weakly interrelated*, then the system is called *near decomposable*. The modifier "*weakly*" is relative. It refers to the property that the interactions among inter-system elements are generally *much weaker* as compared to the interactions among intra-system elements in terms of their intensities (frequencies, strengths and penetration). If these constituents and their constituents and their constituents' constituents, and so on, are all independent, then the system is called *fully decomposable*. A fully decomposable system is not complex, while it can be large in size. On the other hand, a complex system in general is not decomposable, but many of them are near decomposable. It is this latter property providing us a chance to comprehend their behavior. A fully decomposable system can be taken as an *elementary unit* of the built-up complex system.[2]

Here, we are dealing with complexity from two different perspectives, from the system-wide (macro) perspective, i.e., the society (economy, market) as a whole, and second, and from the individual (micro) perspective. For the former, we are asking the questions on how we as human can possibly understand the (evolving) complex systems; for the latter, we are asking the questions on how boundedly rational individuals can possibly harness the information-rich complex environment through learning and adapting so as to making decision and choices effectively.

[2] When we continue decomposing the system down to a level in which near decomposability becomes full decomposability, we say that we have come to the elementary units. Elementary units can still be a system but not a complex system, since their constituents are also independent (admitting full decomposability). In this manner, one may use the physics term *phase transition* to describe a system transiting from the just linearly adding-up to be a complex system by losing its fully-decomposable condition.

3 Modularity

Simon's joint work with Alan Newell on automated theorem proving [15] is often ignored by economists. However, this work is very fundamental since in this project Simon not only used computers to simulate human problem solving processes, but also invented the computer language known as LISP (list processing). This language has been used to understand human problem solving behavior in logic tasks and chess playing. It turns out that LISP not only generates computer programs, but also gives a behavioral model of human information

This is so because LISP is a structural programming [1], which makes extensive use of independent and encapsulated modules (subroutines). This language can work well with the idea of modularity as well as *chunking theory*. The idea of chunks were originally proposed by George Miller [13] as a way to quantifying the short memory capacity (SMC). The well-known Magic Seven means that human's SMC can allow them to distinguish seven plus/minus two chunks of unrelated objects. The original version of Miller's Magic Seven places seven chunks in a flat without a hierarchical structure. The later development of the theory, influenced by the algorithmic information theory, considers a hierarchical structure of chunks so as to extend the short memory capacity [11]. Hence, chunks behave like modules and can be encapsulated as a part of a higher-level chunk and this recursive structure can proceed indefinitely. LISP can then be applied to model the learning behavior through chunking or modularizing. Simon's EPAM (Elementary Perceiver and Memorizer) model is an example [7].

In the early 1960s Simon had already begun the work on the automatic generation of LISP programs, a project called the *heuristic compiler* [19]. The human heuristic searching behavior, characterized by chunking and modularizing, can then be automated and hence simulated by computers. In late 1980s, Nicahel Cramer and John Koza furthered endowed the automatical program generation process with a selection force driven by the Darwinian biological evolution so that the automatically generated programs can become fitter and fitter in terms of some user-defined criteria [5, 10]. This became what was later known as *genetic programming* (GP). GP then provides us a tool to model the automatic learning and discovery processes of the artificial agents so that the artificial agent can be left with a larger degree of autonomy in the environment at which they are situated. This type of agents is known as *autonomous agents*, who have the capability of discovering chances and novelties without supervision. The automatic heuristic search process can be interpreted as an automatic discovery process. If artificial agents are endowed with this function, then they can search and discover on their own without further supervision. The artificial agent with this capability is also called *autonomous agents* (Figure 1, Right Panel).

We have argued in many places that, to be able to make sense of the doctrine of the market economics, what is required from a behavioral or even a cultural viewpoint, is that agents are autonomous [3]. The autonomous agent is the backbone of ACE because ACE normally deals with the theoretical environment which are less regular and not well-defined, such as Hugo in the story, Apple [21].

4 Near Decomposability

Near decomposability is another important concept overarching Simonian economics and ACE. There are two interpretations of near decomposability: a static one and a dynamic one. The former refers to a structure (a graph or a network), and the latter refers to interactions. Since interactions among agents are the essential ingredient of ACE, near decomposability can be interpreted as the Simonian constraint on ACE.

Near decomposability can be considered as Simon's pioneering contribution to the prominent properties of (social) network topology. Simon demonstrated this idea using the matrix notation. This idea can now be well illustrated in the graphical representation of the core-peripheral network. This idea, as a fundamental principle of social interactions, has been repeatedly discovered by sociologists in different forms, such as weak ties [8] structural holes [2], six degrees of separation [12] or three degrees of influence [4]. It is also closely related to the neighborhood-based decisions as frequently used in the grid-based, lattice-based, network-based ACE models [3, 14].

However, Simon's idea of near decomposability is not just at one level, but hierarchically multi-level, which has not been a prototype in ACE. Hence, whether the near-range interactions observed at the bottom-level will necessarily lead to near-range interactions observed at higher levels is not clear. In other words, we don't know yet whether an economy constructed in a multi-level agent-based fashion is near decomposable, or an economy, in general, is near decomposable.

Why is near decomposability so important? Here is the answer that we directly quote from [18].

> If there are important systems in the world that are complex without being hierarchic, they may be a considerable extent escape our observation and our understanding. Analysis of their behavior would involve such detailed knowledge and calculation of the interactions of their elementary parts that it would be beyond our capacities of memory or computation. (Ibid, p. 477)

This sentence is written in the days far before the advent of agent-based, parallel, super, and cloud computing. The big-data era currently presented in front of us clearly shows that memory and computation capacity may no longer be the ultimate concern, although comprehensibility still is. We may be able to simulate a multi-level economy and can examine of the impact of small events, but we may have difficulty tracing the chain of the causes from one level to its immediate next level.

5 Concluding Remarks

In this paper, we argue that even though Simonian economics do have some crosses with ACE, it plays a relative marginal role in ACE. While the hierarchical modularity approach manifested in LISP or genetic programming can be used to model autonomous agents, it is not a mainstream approach taken by the ACE community.

Instead, agents are frequently built upon other methods, such as the entropy maximization principle, generalized reinforcement learning, heuristic switching, or genetic algorithms, which usually do not involve the concept of evolving hierarchical modularity. In this sense, one may infer that the idea of chunking theory as a way to deal with large amount of information and to define an experienced agent is also not followed by most ACE researchers.

Second, the complex system proposed by Simon is both multi-level and near decomposable. Nonetheless, the multi-level agent-based model is also rarely seen in the current practice of ACE. Given the increasing research interest in complex networks (networks of networks, multiplex networks, multi-level networks, and system of cities), one may expect more multi-level agent-based models to appear in the future. By then we may be able to examine whether near decomposability is an essential feature of the complex adaptive system as manifested by ACE.

In sum, even though the major work of Simon outlined in this article has been done before 1970s, it is much ahead of what ACE has been up to today. Hence, it may be fair to say that Simonian economics features more of the future of ACE than its past.

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Incomplete Soft Sets: New Solutions for Decision Making Problems

José Carlos R. Alcantud and Gustavo Santos-García

Abstract Alcantud and Santos-García [2] revisit the soft set based decision making problem under incomplete information. Their solution relies on a classical Laplacian argument from probability theory. In view of the computational characteristics of such algorithm, we propose two related solutions that efficiently evaluate problems with many more incomplete data. A computational analysis assesses the performance of our algorithms and compares them with earlier solutions in the literature.

Keywords Soft set · Incomplete soft set · Decision making

1 Introduction

It is a commonplace to claim that decisions on real life problems usually depend on vague, imprecise or uncertain data. Thus in order to make assessments of these cases, we need to resort to mathematical principles designed for corresponding models. A paradigmatic change in Mathematics was the introduction of a fuzzy set theory which has proven useful for such cases since the seminal Zadeh [12]. Other similarly inspired developments include the theory of soft sets (cf., Molodtsov [8], which includes arguments on some of their applications) and other related models (cf., Alcantud [1]). Maji, Biswas and Roy [6] developed soft set based decision making. Zou and Xiao [13] argued that in the process of collecting data there may be unknown, missing or inexistent data. For this reason incomplete soft sets

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were introduced as a tool to model standard soft sets under incomplete information. Afterwards Han *et al.* [5] and even Qin *et al.* [9] presented other interesting approaches to incomplete soft set based decision making. However, because in general there is perfect uncertainty about the real value of missing data, we cannot support the idea that averages, probabilities or any other specific evaluations allow for generic estimations, as suggested by some authors. Alcantud and Santos-García [2] presented a completely redesigned approach to soft set based decision making problems under incomplete information. In consonance with Laplacian argument of probability theory, these authors examine all completed tables arising from the original incomplete table, which are then evaluated by their respective choice values (cf., [6]) as is standard. Finally, all alternatives are ranked according to the number or proportion of tables with choice value maximizers.

In [2] Alcantud and Santos-García examined the computational costs and concluded that with a large number of missing values, the problem cannot be efficiently solved. Hence in this contribution we propose two modified algorithms that share the original spirit of [2] but permit to tackle problems where uncertainty is larger (in terms of the number of unknown values).

This paper is organized as follows: section 2 recalls some terminology and definitions. Section 3 contains a review of earlier investigations inclusive of [2], as well as our redesigned proposals. In section 4 the computational features of these procedures are examined. Conclusions are drawn in section 5.

2 Definitions: Soft Sets and Incomplete Soft Sets

The usual notation for complete and incomplete soft sets refers to a universe of objects U and a universal set of parameters E.

Definition 1 (Molodtsov [8]). A pair (F, A) is a *soft set* over U when $A \subseteq E$ and $F : A \longrightarrow \mathcal{P}(U)$, where $\mathcal{P}(U)$ denotes the set of all subsets of U.

Such (F, A) is regarded as a parameterized family of subsets of U, the set A being the parameters. For each parameter $e \in A$, $F(e)$ is the subset of U approximated by e or the set of e-approximate elements of the soft set.

Soft sets and related concepts have been widely investigated. Maji, Bismas and Roy [7] defined soft subsets and supersets, soft equalities, intersections and unions of soft sets. Feng and Li [4] provided an extensive study of several types of soft subsets and soft equal relations. The fundamental reference for soft set based decision making draws on Maji, Biswas and Roy [6], but other extensions and applications of soft sets can be found in e.g., [3, 9, 10].

The incomplete soft set notion leads on to a more general scenario:

Definition 2 (Han *et al.* [5]). A pair (F, A) is an *incomplete soft set* over U when $A \subseteq E$ and $F : A \longrightarrow \{0, 1, *\}^U$, where $\{0, 1, *\}^U$ is the set of all functions from U to $\{0, 1, *\}$.

The $*$ symbol in Definition 2 means lack of information: when $F(e)(u) = *$ we do not know whether u belongs to the subset of U approximated by e or not. As in the analysis of soft sets, $F(e)(u) = 1$ (resp., $F(e)(u) = 0$) means that u belongs (resp., does not belong) to the subset of U approximated by e. Obviously, every soft set can be considered an incomplete soft set.

In applications both U and A are usually finite. Standard soft sets can be represented either by matrices or in matrix/tabular form (cf., Yao [11]): rows are attached with objects in U, and columns are attached with parameters in A. These representations are binary (i.e., all cells are either 0 or 1). In incomplete soft sets, one can proceed similarly, the possible values for cells being 0, 1, $*$.

Concerning (standard) soft set based decision making, the fundamental reference is Maji, Biswas and Roy [6]. When a soft set (F, A) is represented in matrix form through the $k \times l$ matrix (t_{ij}), where k and l are the cardinals of U and A respectively, then the *choice value* of an object $h_i \in U$ is $c_i = \sum_j t_{ij}$. A suitable choice is made when the selected object h_k verifies $c_k = \max_i c_i$: objects that maximize the choice value are satisfactory outcomes of the problem.

Example 1 below shows a matrix representation for an incomplete soft set:

Example 1. Let $U = \{h_1, h_2, h_3\}$ be a universe of houses. Let $E = \{e_1, e_2, e_3, e_4\}$ the set of parameters, attributes or house characteristics. Define an incomplete soft set (F, E) as follows:

1. $h_1 \in F(e_1) \cap F(e_4)$, $h_3 \notin F(e_2) \cup F(e_3)$.
2. $h_2 \in F(e_1) \cap F(e_3)$, $h_1 \notin F(e_4)$. It is unknown whether $h_1 \in F(e_2)$ or not.
3. $h_3 \in F(e_2)$, $h_2 \notin F(e_3) \cup F(e_4)$. It is unknown whether $h_2 \in F(e_1)$ or not.

Table 1 captures the information defining (F, E). We have two unknown values ($w = 2$), and we enumerate the cells with value $*$ as $((1, 2), (2, 1))$. For each $v \in \{0, 1\}^w$, one feasible completed table arises, that is, $\{v_1 = (0, 0), v_2 = (0, 1), v_3 = (1, 0), v_4 = (1, 1)\}$. These four tables are represented in Table 1, together with the corresponding choice values of the houses. Note that h_1 reaches the highest choice value c_i in all these tables, h_2 reaches the highest choice value in C_2 only, and h_3 reaches the highest choice value exactly in C_1 and C_2.

3 Algorithms: Probabilistic Incomplete Soft Sets for Decision Making Problem

In this section we refer to a decision making practice under incomplete soft sets. In this regard, the most successful approaches are probably the following:

1. Zou and Xiao [13] initiated the analysis of soft sets and fuzzy soft sets under incomplete information. They proposed a standard case to calculate all possible choice values for each object, and then calculated their respective *decision values* d_i by the method of weighted-average. To this purpose the weight of each possible

Table 1 (a) Tabular representation C of the incomplete soft set (F, E) in Example 1. (b)-(e) The four completed tables C_i for (F, E) with corresponding choice values c_i.

(a) C matrix

	e_1	e_2	e_3	e_4
h_1	1	0	0	1
h_2	1	$*$	1	0
h_3	$*$	1	0	0

(b) C_1 matrix

	e_1	e_2	e_3	e_4	c_i
h_1	1	0	0	1	2
h_2	1	0	1	0	2
h_3	0	1	0	0	1

(c) C_2 matrix

	e_1	e_2	e_3	e_4	c_i
h_1	1	0	0	1	2
h_2	1	0	1	0	2
h_3	1	1	0	0	2

(d) C_3 matrix

	e_1	e_2	e_3	e_4	c_i
h_1	1	0	0	1	2
h_2	1	1	1	0	3
h_3	0	1	0	0	1

(e) C_4 matrix

	e_1	e_2	e_3	e_4	c_i
h_1	1	0	0	1	2
h_2	1	1	1	0	3
h_3	1	1	0	0	2

choice value is computed by existing complete information. Some simple indicators that can eventually be used to prioritize the alternatives include $c_{i(0)}$ (choice value when all missing data are 0), $c_{i(1)}$ (choice value when all missing data are 1) and d_{i-p} which coincides with $(c_{i(0)} + c_{i(1)})/2$.

2. Inspired by this idea, Qin *et al.* [9] proposed a novel way to fill the missing data in an incomplete soft set. They prioritized the association between parameters rather than the probability of objects appearing in $F(e_i)$.

3. Han *et al.* [5] developed and compared several elicitation criteria for decision making of incomplete soft sets which are generated by restricted intersection.

4. Alcantud and Santos-García [2] examined all completed tables arising from the original incomplete table. Their choice values are computed as in [6]. Finally, the alternatives are ranked by the proportion of tables in which these objects are choice value maximizers.

3.1 Algorithm (Version 1)

Since in general there is perfect uncertainty about the real value of the absent data in an incomplete soft set, in [2] we proposed a completely different approach. We evaluate each feasible filled table according to their choice value. We order a significative sample of the alternatives by the proportion of tables in which each alternative receives the highest choice value.

Herewith we present an intuitive exposition of our proposal: according to Laplace's principle of indifference in probability theory, under complete ignorance we must assume that in all tables $*$'s are replaced in equiprobable manner with either 0 or 1. Hence the best we can do is compute in each of these cases the objects should be selected according to soft-set based decision making procedures, and consequently opt for any object that is optimal in the highest proportion of cases with the completed information. Due to the large number of possible cases, which is exponential on the number of unknown values, we choose a small and sufficient sample.

In accordance with this idea, we endorse the following algorithm for the problems where both U and A are finite. Initially, we consider an incomplete soft set (F, E) in a matrix form. Any cell (i, j) is denoted by $t_{ij} \in \{0, 1, *\}$. The cells with incomplete values can be enumerated as a set of pairs $((i_1, j_1), \dots, (i_w, j_w))$, where w is the number of unknown values.

Algorithm 1. Incomplete Soft Sets Algorithm for Making Decision (version 1)

1: Input an incomplete soft set (F, E) with k objects and l parameters in a matrix form, where $t_{ij} \in \{0, 1, *\}$ denotes a cell (i, j).

2: Select the cells with value $*$ as the set of pairs $\{(i_1, j_1), \dots, (i_w, j_w)\}$.

3: From Step 2, select both a significative random sample (size K) of distinct pairs set and random values $v_z \in \{0, 1\}$ for each pair (i_z, j_z).

4: For each vector $v = (v_1, \dots, v_w) \in \{0, 1\}^w$ in Step 3, construct a $k \times l$ matrix $C_v = (c_{ij})$ where:

$$c_{ij} = \begin{cases} v_z & \text{if } (i, j) = (i_z, j_z) \text{ is listed in } \{(i_1, j_1), \dots, (i_w, j_w)\} \\ t_{ij} & \text{otherwise} \end{cases}$$

5: For each object u_i, calculate $s_i^1 = n_i / K$, where n_i denotes the number of vectors v for which object i maximizes the choice value at C_v in Step 4.

6: Finally, the result of the decision is any object u_l such that $s_l^1 = \max_{i=1,\dots,k} s_i^1$.

We select a random significative sample of size K of a pair set and random values v_z for each pair. This is the keystone because the number of possibilities is 2^w, which is unmanageable when the value w is large.

For each vector $v = (v_1, \dots, v_w) \in \{0, 1\}^w$, we construct a $k \times l$ matrix $C_v = (c_{ij})$ where each cell is equal to t_{ij} for known values and a random value (0 or 1) for unknown values.

Now we calculate $s_i^1 = n_i / K$, where n_i denotes the number of vectors v for which object i maximizes the choice value in C_v. Finally, the decision is any object u_l that maximizes the score computed, i.e., any u_l such that $s_l^1 = \max_{i=1,\dots,k} s_i^1$.

3.2 *Algorithm (Version 2)*

Now we consider a variant of our algorithm. Initially, we also consider an incomplete soft set (F, E) in a matrix form. Any cell (i, j) is denoted by $t_{ij} \in \{0, 1, *\}$.

Algorithm 2. Incomplete Soft Sets Algorithm for Making Decision (version 2)

1: Input an incomplete soft set (F, E) with k objects and l parameters in a matrix form, where $t_{ij} \in \{0, 1, *\}$ denotes a cell (i, j).
2: Calculate $c_0 = \max_{1 \leq i \leq k} c_{i(1)}$ from the incomplete matrix, where $c_{i(0)}$ is the choice value if all missing data are assumed to be 0.
3: Remove each row i from the incomplete matrix that verifies $c_{i(1)} < c_1$, where $c_{i(1)}$ is the choice value if all missing data are assumed to be 1.
4: From the new reduced matrix, select the cells with value $*$ as the set of pairs $\{(i_1, j_1), \ldots, (i_w, j_w)\}$.
5: From the previous step, select a significative random sample (size K) of pairs set and random values v_z (0 or 1) for each pair (i_z, j_z).
6: For each vector $v = (v_1, \ldots, v_w) \in \{0, 1\}^w$, construct a $k \times l$ matrix $C_v = (c_{ij})$ where:

$$c_{ij} = \begin{cases} v_z & \text{if } (i, j) = (i_z, j_z) \text{ is listed in } \{(i_1, j_1), \ldots, (i_w, j_w)\} \\ t_{ij} & \text{otherwise} \end{cases}$$

7: For each object u_i, calculate $s_i^2 = n_i / K$, where n_i denotes the number of vectors v for which object i maximizes the choice value at C_v.
8: Finally, the result of the decision is any object u_l such that $s_l^2 = \max_{i=1,\ldots,k} s_i^2$.

The difference is that now we carry out a pre-screening operation before taking a sample of all possible cases of matrix completion. First, we calculate the maximum value c_0 of the choice value $c_{i(0)}$ for all objects u_i. If this value is unattainable for the choice value $c_{i(1)}$ of an object u_i, i.e., if all missing data are assumed to be 1, this object can be removed from the initial matrix.

This sieve is particularly important because the number of cases is exponential with respect to the number w of missing data. In this version of the algorithm, by reducing the number of rows, there is less potential missing data, which reduces runtime and improves final results.

After this simplification, we apply the other steps in the same way as in the first version of the algorithm to the new trimmed matrix.

4 Experimental Results

4.1 Indicators Comparison

We proceed to compare our proposal with some solutions provided by the literature. We refer to procedures for the prioritization of the objects defined in section 3. For this purpose, we consider an easily reproducible and large enough matrix:

Example 2. We design the following T, a matrix associated with an incomplete soft set (F_1, E_1) with n objects and m parameters. Let π_i be the i-th decimal number of π. We let $\pi_i' = *$ if $\pi_i = 0$, $\pi_i' = 0$ if $\pi_i > 6$, and $\pi_i' = 1$ otherwise. Then $n \times m$ numbers π_i' are used to fill by rows the whole matrix T.

Table 2 Indicators by several focal proposals and optimal solutions for the incomplete soft set (F_1, E_1) in Example 2.

	d_i	d_{i-p}	$c_{i(0)}$	$c_{i(1)}$	s_i	s_i^1	s_i^2
a_1	6.0000	6.0000	6.0000	6.0000	0	0	0
a_2	7.4000	7.5000	7.0000	8.0000	0.0625	0.0612	0.1429
a_3	8.7273	9.0000	8.0000	10.0000	0.8125	0.8080	0.8571
a_4	7.6818	8.5000	7.0000	10.0000	0.5000	0.5062	0.2143
a_5	6.5000	7.0000	6.0000	8.0000	0.0312	0.0297	0
a_6	5.7000	6.0000	5.0000	7.0000	0	0	0
a_7	5.9455	6.5000	5.0000	8.0000	0.0156	0.0156	0
a_8	5.7545	6.0000	5.0000	7.0000	0	0	0
a_9	6.4455	6.5000	5.0000	8.0000	0.0156	0.0160	0.0714
a_{10}	6.2727	6.5000	6.0000	7.0000	0	0	0
a_{11}	5.5000	5.5000	5.0000	6.0000	0	0	0
a_{12}	7.0000	7.0000	7.0000	7.0000	0	0	0
Optimal	$\{a_3\}$	$\{a_3\}$	$\{a_3\}$	$\{a_3, a_4\}$	$\{a_3\}$	$\{a_3\}$	$\{a_3\}$

In order to analyze this artificial situation, Table 2 collects several indicators proposed by previous procedures plus s_i^1 and s_i^2 in Algorithms 1 and 2. In Example 2, when $n = 12$ and $m = 20$ there are 20 unknown values. This example readily shows that our proposal of solution provides similar but distinct solutions than those suggested by either the $c_{i(0)}$, $c_{i(1)}$ or s_i indicators [2].

4.2 Performance of the Algorithms

To evaluate the performance of proposed algorithms, we show in Table 3 the runtimes for different dimensions of some matrices of incomplete soft sets: (a) $n = 50$,

Table 3 Matlab implementation performance of our Algorithms for $K = 1,000$. Running times in seconds.

	Matrix Dimensions (n, m)					
	(50, 200)			(100, 500)		
# unknown values	s_1	s_1^1	s_1^2	s_1	s_1^1	s_1^2
10	0.2331	0.2160	0.0008	0.4128	0.3439	0.0763
11	0.4726	0.2169	0.0008	0.8252	0.3446	0.0013
12	0.9245	0.2162	0.0007	1.5072	0.3455	0.0016
13	2.0415	0.2146	0.0006	2.9577	0.3474	0.0015
14	3.8883	0.2141	0.0006	5.8508	0.3435	0.0015
15	7.3964	0.2164	0.0007	12.2864	0.3413	0.0014
16	15.4481	0.2199	0.0007	26.9188	0.3434	0.0015

$m = 200$; (b) $n = 100$, $m = 500$. For each matrix size and different number of unknown values, we calculate the choice values s_i [2] and the current choice values s_i^1 and s_i^2. For the latter we have taken a value K equal to $1,000$. Each value in Table 3 represents the average runtime in seconds of our Algorithms for 10 random examples of matrices with the same conditions.

The Algorithms we have developed are written in R2014b Matlab language. We run it on a Mac computer with OSX Yosemite system, processor Intel Core i5 CPU I5-2557M at 1,7 GHz and 4 GB RAM.

5 Final Comments and Conclusion

We have shown that the Laplacian criterion for soft set based decision making problems under incomplete information in Alcantud and Santos-García [2] can be refined so as to deal with problems with larger uncertainty, measured by the number w of unknown items, in an efficient manner. The computational analysis encouraged us to develop related algorithms that enhance our assumptions and solve cases which require a long runtime. Here we have used two related techniques. It may be possible to select a sample of the 2^w possible matrices in such a way that with a sufficiently large number of samples, the estimate of our coefficient $\bar{s}_i$ is deemed reliable enough. In addition, we can trim the matrix so as to eliminate options that would never attain the highest choice value, irrespective of the data that may fill in the data matrix.

One possible direction for further research is the extension of our Laplacian approach to decision making of incomplete soft sets generated by restricted intersections (cf., Han *et al.* [5]). It may also be possible to exploit the fact that when there are several missing data for an option, the result of its choice value only depends on the number of alternatives that are completed with a 1 because choice values are computed by addition. Therefore a non-trivial combinatorial problem should be solved prior to implementing an improved algorithm that benefits from such feature.

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A Mixed Model of Optimal Saving

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Abstract This paper proposes a mixed model to study a consumer's optimal saving in the presence of two types of risk: income risk and background risk. In this model the income risk is represented by a fuzzy number and the background risk by a random variable. Three notions of precautionary saving are defined as indicators of the extra saving induced by the income and the background risk on the consumer's optimal choice.

Keywords Saving · Background risk · Income risk · Possibility theory

1 Introduction

The recent economics literature describes many hypotheses that may account, either individually or jointly, for the extraordinary saving rates of the Chinese households (see e.g. [11]). However, very few of these explanations could be reconciled with the complex empirical reality of that country. One of the most prominent and successful hypothesis is based on the theory of relative consumption: Chinese people care not only about their individual consumption levels, but also very particularly about their relative affluence in their social environment. In the context of a rapidly growing economy like the Chinese, Harbaugh (1996) [10] proved that the fear of falling

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behind is likely to be intensified and generate higher precautionary saving. However, the social acceptability of a person with a certain income level is itself fuzzy and difficult to establish. Chinese people are uncertain about the future income boundaries that will determine their membership status with respect to different social groups. Therefore, fuzzy reasoning and fuzzy optimization can become a valuable tool to anticipate their saving behavior: their incomes will be associated to different utility levels depending on their expected social success, which is itself a fuzzy concept. Our novel theoretical analysis can be useful as a conceptual basis for numerical evaluations of a countrys saving potential. Such basis is therefore embedded in its social structure, which must be analyzed simultaneously.

Nowadays it is widely expressed a concern about the huge saving rate of Chinese households, which has far-reaching international implications in terms of China's current account surpluses and the Western external deficits. Many analysts and policy makers are trying to trace back the reasons for such behavior and predict how long it will last. In this regard, many of the potential explanations for this phenomenon point to economic uncertainty as a determinant of precautionary saving ([2]). In contrast to the Chinese example, European and U.S. households are well known for their low saving rates, which calls for some precise explanations as well ([13]). Both the kind of uncertainty and the features of the consumers' preferences must be analyzed, in order to predict micro or macroeconomic saving patterns. In this context, the notion of precautionary saving has long appeared in models of economic decision under uncertainty. It measures the way adding a source of risk modifies the optimal saving. When the consumer's utility function is unidimensional and the risk situation is described by a random variable, extra saving will appear in response to uncertainty when the third order derivative of the utility function is positive. On the other hand, several authors ([4], [9]) studied economic decision processes governed by two types of risk: primary risk (income risk) and background risk (loss of employment, divorce, illness, etc.). In our paper, as in [12], the presence of background risk will be associated to a nonfinancial variable and will be uninsurable, nevertheless having an influence on the optimal solution for economic decisions (see e.g.[5]).

The way the interaction of both types of risk affects optimal saving was studied by [3] and [12]. These models assume that the consumer's activity takes place during two periods and both types of risk act during the second period. The presence or the absence of one of the two types of risk leads to several possible uncertainty situations, which enables the definition of several notions of precautionary saving (e.g. [12] two of such notions are studied).

All the optimal saving models in the literature are based on probability theory. That is, both the primary and the background risk are modeled as random variables. However, there are risk situations for which probabilistic models are not appropriate (e.g. for small databases). Zadeh's possibility theory [15] offers another way to model some risk situations. Here risk is modeled with possibility distributions (particularly, with fuzzy numbers) and the well known probabilistic indicators (e.g. expected value, variance, covariance) are replaced by the corresponding possibilistic indicators. Due to the complexity of economic and financial phenomena, one can have mixed situations in which some risk parameters should be probabilistically modeled with random variables, and other risk parameters should be possibilistically modeled with fuzzy numbers. Then we can consider the following four possible situations: (1) a random variable captures the primary risk and also a random variable captures the background risk; (2) a fuzzy number captures the primary risk and a fuzzy number captures the background risk; (3) a fuzzy number captures the primary risk and a random variable captures the background risk; (4) a random variable captures the primary risk and a fuzzy number captures the background risk.

The situation (1) was treated in the abovementioned probabilistic models. The purpose of this paper is to study the precautionary saving motive in situation (3). In case of situation (3), the risk situation is described by a mixed vector (A, X), where A is a fuzzy number and X is a random variable. Let us denote the mixed models described by situation (3) as type I models. We will also denote the mixed models described by situation (4) as type II models. For type I models we will define three notions of precautionary saving and investigate the necessary and sufficient conditions for extra saving to arise, after adding primary risk, background risk or both of them. The main results of the paper establish those necessary and sufficient conditions, expressed in terms of third-order partial derivatives of the bidimensional utility function and in terms of the probabilistic and possibilistic variances associated with the mixed vector.

Our three notions of precautionary saving will be defined below in detail. However, we can anticipate that the first notion refers to the extra saving arising when a small income risk is introduced, relative to the optimal saving under certainty. The second notion refers to the extra saving arising when a small background risk is introduced, relative to the optimal saving under certainty. And finally, the third notion refers to the extra saving arising when both a small income risk and a small background risk are introduced, relative to the optimal saving under certainty. Each of the three notions requires its own necessary and sufficient conditions for each kind of precautionary saving to be positive. We will describe now briefly the structure of the paper. Section 2 recalls the indicators of fuzzy numbers and the mixed expected utility of [8]. Section 3 presents the mathematical framework in which the optimal saving models with background risk are embedded. Section 4 proposes mixed models of optimal saving of type I, with an income risk modeled with a fuzzy number and a background risk modeled with a random variable.

2 Preliminaries

Let us now introduce some preliminary concepts on fuzzy theory. Let X be a non–empty set of states. A fuzzy subset of X is a function $A : X \rightarrow [0, 1]$. A fuzzy set A is normal if $A(x) = 1$ for some $x \in X$. The support of A is defined by $supp(A) = \{x \in \mathbf{R} | A(x) > 0\}$. Assume $X = \mathbf{R}$. For $\gamma \in [0, 1]$, the γ–level set $[A]^\gamma$ is defined by

$$[A]^\gamma = \begin{cases} \{x \in \mathbf{R} | A(x) \geq \gamma\} \text{ if } \gamma > 0 \\ cl(supp(A)) \text{ if } \gamma = 0 \end{cases}$$

The fuzzy set A is fuzzy set if $[A]^\gamma$ is a convex subset of $\mathbf{R}$ for all $\gamma \in [0, 1]$. A fuzzy subset A of $\mathbf{R}$ is a *fuzzy number* if it is normal, fuzzy convex, continuous and with bounded support. If A, B are fuzzy numbers and $\lambda \in \mathbf{R}$ then the fuzzy numbers $A + B$ and λA are defined by

$$(A + B)(x) = \sup_{y+z=x} \min(A(y), B(z))$$
$$(\lambda A)(x) = \sup_{\lambda y=x} A(y)$$

A non–negative and monotone increasing function $f : [0, 1] \to \mathbf{R}$ is a *weighting function* if it satisfies the normality condition $\int_0^1 f(\gamma)d\gamma = 1$. Let f be a weighting function and $u : \mathbf{R} \to \mathbf{R}$ a continuous utility function. Assume that A is a fuzzy number whose level sets have the form $[A]^\gamma = [a_1(\gamma), a_2(\gamma)]$ for any $\gamma \in [0, 1]$.

The possibilistic expected utility $E(f, u(A))$ is defined by:

(1) $E(f, u(A)) = \frac{1}{2} \int_0^1 [u(a_1(\gamma)) + u(a_2(\gamma))] f(\gamma)d\gamma$

If u is the identity function of $\mathbf{R}$ then $E(f, u(A))$ is the possibilistic expected value [1]:

(2) $E(f, A) = \frac{1}{2} \int_0^1 [a_1(\gamma) + a_2(\gamma)] f(\gamma)d\gamma$

If $u(x) = (x - E(f, A))^2$ for any $x \in \mathbf{R}$ then $E(f, u(A))$ is the possibilistic variance [1]:

(3) $Var(f, A) = \frac{1}{2} \int_0^1 [(a_1(\gamma) - E(f, A))^2 + (a_2(\gamma) - E(f, A))^2] f(\gamma)d\gamma$

3 Mixed Expected Utilities

The concept of mixed expected utility was introduced in [8] in order to build a model of risk aversion with mixed parameters: some of them were described by fuzzy numbers and others by random variables. This same notion has been used in [7] to study mixed investment models in the presence of background risk. In this section we will review this definition of mixed expected utility and some of its properties. For clarity purposes, we will deal only with the bidimensional case. Then a mixed vector will have the form (A, X), where A is a fuzzy number and X a random variable. Without loss of generality, we will only consider the case (A, X). Let X be a random variable w.r.t. a probability space $(\Omega, \mathcal{K}, P)$. We will denote by $M(X)$ its expected value and by $Var(Y)$ its variance. If $u : \mathbf{R} \to \mathbf{R}$ is a continuous function, then $u(X) = u \circ X$ is a random variable and $M(u(X))$ is the probabilistic expected utility of X w.r.t. u.

We fix a weighting function f and a bidimensional, continuous utility function $u : \mathbf{R}^2 \to \mathbf{R}$. Let (A, X) be our particular mixed vector. Assume that the level sets of A have the form $[A]^\gamma = [a_1(\gamma), a_2(\gamma)]$, $\gamma \in [0, 1]$. For any $a \in \mathbf{R}$, $u(a, X) : \Omega \to \mathbf{R}$ will be the random variable defined by $u(a, X)(w) = u(a, X(w))$ for any $w \in \Omega$.

Let us now define our concept of mixed expected utility, which will be subject to maximization in our approach to optimal saving.

Definition 3.1. *([6], [8]) The mixed expected utility* $E(f, u(A, X))$ *associated with* f, u *and the mixed vector* (A, X) *is defined by:*
$E(f, u(A, X)) = \frac{1}{2}\int_0^1 [M(u(a_1(\gamma), X)) + M(u(a_2(\gamma), X))] f(\gamma) d\gamma$

4 A Probabilistic Approach to Optimal Saving

The optimal saving models presented in [3] and [12] consider the existence of two types of risk, background risk and income risk, both of them being mathematically represented by random variables. In this section we will present the general features of these models as a reference to start building our main models in the following sections. These two-period models proposed by [3] and [12] are characterized by the following data:

- $u(y, x)$ and $v(y, x)$ are consumer's utility functions for period 0, resp. 1.
- the variable y represents the income, and x is a non-financial variable.
- for period 0, the variables x and y have the certain values x_0 and y_0.
- for period 1, there is an uncertain income (described by the random variable Y) and a background risk (described by the random variable X).

We denote $\bar{y} = M(Y)$ and $\bar{x} = M(X)$. In [12] the author mentions the following four possible situations for the variables y and x :

(a) $y = Y, x = X$ (simultaneous presence of income risk and background risk) (b) $y = Y, x = \bar{x}$ (income risk and no background risk) (c) $y = \bar{y}, x = X$ (background risk and no income risk) (d) $y = \bar{y}, x = \bar{x}$ (no uncertainty)

Consider now the following expected lifetime utilities corresponding to the situations (a), (c) and (d), respectively:

(1) $V(s) = u(y_0 - s, x_0) + M(v(Y + s, X))$
(2) $W(s) = u(y_0 - s, x_0) + M(v(\bar{y} + s, X))$
(3) $T(s) = u(y_0 - s, x_0) + v(\bar{y} + s, \bar{x})$

where s is the level of saving. According to [12], the optimization problem can be formulated as follows:

(4) $\max_s V(s) = V(s^*)$
(5) $\max_s W(s) = W(s^\circ)$
(6) $\max_s T(s) = T(s^{\circ\circ})$

with the optimal solutions $s^* = s^*(Y, X)$, $s^\circ = s^\circ(\bar{y}, X)$, $s^{\circ\circ} = s^{\circ\circ}(\bar{y}, \bar{x})$.

The differences $s^* - s^\circ$, $s^* - s^{\circ\circ}$ are called precautionary saving and two-source precautionary saving, respectively. In [12]. Menegatti finally presents some necessary and sufficient conditions such that $s^* - s^\circ \geq 0$ and $s^* - s^{\circ\circ} \geq 0$, which generalize some results previously obtained in [3].

5 Mixed Models of Type I

The mixed models of this section are based on the hypothesis that the income risk is described by a fuzzy number A and the background risk is described by a random variable X. We will preserve the notation introduced in the previous section. A fuzzy number A corresponds to the variable y and the random variable X corresponds to the variable x. Thus instead of Menegatti's random vector (Y, X) [12] we have a mixed vector (A, X).

We will fix a weighting function f and denote $a = E(f, A)$ and $\bar{x} = M(X)$. In this case the situations (a)–(d) of Section 4 become

(a_1) $y = A, x = X$
(b_1) $y = A, x = \bar{x}$
(c_1) $y = a, x = X$
(d_1) $y = a, x = \bar{x}$

In this section we will study how the optimal saving changes as we follow the routes $(c_1) - -(a_1)$, $(d_1) - -(a_1)$ and $(b_1) - -(a_1)$. The first two are analogous to the cases studied in [12] for the probabilistic models. We will define three notions of "precautionary saving" and will establish necessary and sufficient conditions for the positivity of these indicators. Assume that the bidimensional utility functions u and v are strictly increasing with respect to each component, strictly concave and three times continuously differentiable. We denote by u_i, u_{ij} , u_{ijk} (resp. v_i, v_{ij}, v_{ijk}) the first, the second and the third partial derivatives of u (resp. v).

Next we will use, as in [12], the following Taylor approximation:

(1) $v_1(y + s, x) \approx v_1(a + s, \bar{x}) + v_{11}(a + s, \bar{x})(y - a) + v_{12}(a + s, \bar{x})(x - \bar{x})+$
$\frac{1}{2}[v_{111}(a+s, \bar{x})(y-a)^2 + v_{122}(a+s, \bar{x})(x-\bar{x})^2 + 2v_{112}(a+s, \bar{x})(y-a)(x-\bar{x})$

Using the notion of mixed expected utility, we introduce the following expected lifetime utilities:

(2) $V_1(s) = u(y_0 - s, x_0) + E(f, v(A + s, X))$
(3) $W_1(s) = u(y_0 - s, x_0) + E(f, v(a + s, X)) = u(y_0 - s, x_0) + M(a + s, X)$
(4) $T_1(s) = u(y_0 - s, x_0) + v(a + s, \bar{x})$
(5) $U_1(s) = u(y_0 - s, x_0) + E(f, v(A + s, \bar{x}))$

V_1, W_1, T_1 are the possibilistic analogues of V, W, T and U_1 comes from the situation (b_1) from above. By taking into account our formula (1) from Section 2:

(6) $V_1(s) = u(y_0 - s, x) + \frac{1}{2}\int_0^1 [M(v_1(a_1(\gamma) + s, X)) + M(v_1(a_2(\gamma) + s, X))]f(\gamma)d\gamma$

If we differentiate, from (6) one obtains:

$V_1'(s) = -u_1(y_0 - s, x_0) + \frac{1}{2}\int_0^1 [M(v_1(a_1(\gamma) + s, X)) + M(v_1(a_2(\gamma) + s, X))]f(\gamma)d\gamma$

which, by formula (1) of Section 2, can be written as

(7) $V_1'(s) = -u_1(y_0 - s, x_0) + E(f, v_1(A + s, X))$

If we differentiate, from (3)-(5) it follows that:

(8) $W_1'(s) = -u_1(y_0 - s, x_0) + M(v_1(a + s, X))$
(9) $T_1'(s) = -u_1(y_0 - s, x_0) + v_1(a + s, \bar{x}))$
(10) $U_1'(s) = -u_1(y_0 - s, x_0) + E(f, v_1(A + s, \bar{x}))$

Proposition 5.1. *The functions V_1, W_1, T_1, U_1 are strictly concave.*

We consider now the following optimization problems:
(11) $\max_s V_1(s) = V_1(s^*)$
(12) $\max_s W_1(s) = W_1(s^\circ)$
(13) $\max_s T_1(s) = T_1(s^{\circ\circ})$
(14) $\max_s U_1(s) = U_1(s^\Delta)$
in which $s_1^* = s_1^*(A, X)$, $s_1^\circ = s_1^\circ(a, X)$, $s_1^{\circ\circ} = s_1^{\circ\circ}(a, \bar{x})$, $s_1^\Delta = s_1^\Delta(A, \bar{x})$ are optimal solutions.

By Proposition 5.1, the four optimal solutions are given by:
$V_1'(s_1^*) = 0$, $W_1'(s_1^\circ) = 0$, $T_1'(s_1^{\circ\circ}) = 0$, $U_1'(s_1^\Delta) = 0$
Taking into account (7)-(10), the optimal conditions are written:
(15) $u_1(y_0 - s_1^*, x_0) = E(f, v_1(A + s_1^*, X))$
(16) $u_1(y_0 - s_1^\circ, x_0) = M(v_1(a + s_1^\circ, X))$
(17) $u_1(y_0 - s_1^{\circ\circ}, x_0) = M(v_1(a + s_1^{\circ\circ}, X)) = v_1(a + s_1^{\circ\circ}, \bar{x})$
(18) $u_1(y_0 - s_1^\triangle, x_0) = E(f, v_1(a + s_1^\triangle, \bar{x}))$

Following the line of [12], we will introduce three notions of "mixed precautionary saving": $s_1^* - s_1^\circ$, $s_1^* - s_1^{\circ\circ}$, $s_1^* - s_1^\triangle$.

$s_1^* - s_1^\circ$ corresponds to precautionary saving from [12] and measures the modification of the optimal saving when moving from $(y = a, x = X)$ to $(y = A, x = X$, i.e. by adding the income risk A in the presence of the background risk X. The difference $s_1^* - s_1^{\circ\circ}$ expresses the modification of the optimal saving by moving from the certain situation $(y = a, x = \bar{x})$ to the situation $(y = A, x = X)$, i. e. by adding the income risk A and the background risk X. Finally, $s_1^* - s_1^\triangle$ measures the modification of the optimal saving by moving from $(y = A, x = \bar{x})$ to $(y = A, x = X)$, i.e. by adding the background risk X in the presence of the income risk A. Next we intend to give necessary and sufficient conditions for the positivity of the three indicators.

Proposition 5.2. *Let (A, X) be a mixed vector with $a = E(f, A)$ and $\bar{x} = M(X)$. The following equalities are equivalent: (i) $s_1^*(A, X) - s_1^\circ(a, X) \geq 0$; (ii) $v_{111}(a + s_1^*(A, X), \bar{x}) \geq 0$.*

The property (i) of the previous proposition says that the effect of adding the income risk A in the presence of background risk X is the increase in the optimal saving. In particular, from Proposition 5.2 it follows that if $v_{111} > 0$ then $s_1^*(A, X) - s_1^\circ(a, X) \geq 0$ for any income risk A and for any background risk X. Next we study the change of the optimal saving on the route $(d_1) \to (a_1)$.

Proposition 5.3. *Let (A, X) be a mixed vector with $a = E(f, A)$ and $\bar{x} = M(X)$. The following equalities are equivalent: (i) $s_1^*(A, X) - s_1^{\circ\circ}(a, \bar{x}) \geq 0$; (ii) $v_{111}(a + s_1^*(A, X), \bar{x}) Var(f, A) + v_{122}(a + s_1^*(A, X), \bar{x}) Var(X) \geq 0$.*

Condition (i) of Proposition 5.3 says that the effect of adding the income risk A and the background risk X is the increase in the optimal saving. In particular, from

Proposition 5.3 it follows that if $v_{111} > 0$ and $v_{122} > 0$ then for any mixed vector (A, X) we have $s_1^* - s_1^{\circ\circ} \geq 0$.

Corollary 5.4. *Assume that* (A, X) *is a mixed vector and* $s_1^*(A, X) - s_1^{\circ}(a, X) \geq 0$. *If* $v_{122} > 0$ *then* $s_1^*(A, X) - s_1^{\circ\circ}(a, \bar{x}) \geq 0$, *where* $a = E(f, A)$ *and* $\bar{x} = M(X)$.

Finally consider now the change of the optimal saving on the route $(b_1) \to (a_1)$.

Proposition 5.5. *Let* (A, X) *be a mixed vector with* $a = E(f, A)$ *and* $\bar{x} = M(X)$. *The following equalities are equivalent: (i)* $s_1^*(A, X) - s_1^{\triangle}(A, \bar{x}) \geq 0$; *(ii)* $v_{122}(a + s_1^*(A, X), \bar{x}) \geq 0$

Condition (i) of the previous proposition says that adding the background risk X in the presence of the income risk A leads to an increase in the optimal saving.

Corollary 5.6. *If* $s_1^* - s_1^{\circ} \geq 0$ *and* $s_1^* - s_1^{\triangle} \geq 0$ *then* $s_1^* - s_1^{\circ\circ} \geq 0$.

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The Role of Technological Changes in Foreign-Exchange Market Inefficiency

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Abstract To study market inefficiency which comes from rapidly developing software and technological progress in whole, we introduce technological bias in the exchange-rate market. The idea of technological bias emerges from the fact that recently innovative approaches have been used to solve trading tasks and to find the best trading strategies. If we consider the same pace of technological progress of trading infrastructure and computational tools along with software in the coming years, the traders who are able to adapt to this technological changes will get more profitable trading solutions than those who will require more time to adjust. Described situation displays market inefficiencies that challenge the idea of the efficient market theory, but are in line with adaptive market hypothesis. To support our suggestion about technological bias we compare the performance of deep learning methods, shallow neural network with ARIMA method and random walk model using daily closing between three currency pairs: Euro and US Dollar (EUR/USD), British Pound and US Dollar (GBP/USD), and US Dollar and Japanese Yen (USD/JPY). The results reveal the convincing accuracy of deep neural networks comparing to the other methods demonstrating the capacity of new computational methods based on evolving software. Shallow neural network outperform random walk model that confirms the idea of market inefficiency, but cannot surpass ARIMA accuracy significantly.

Keywords Technological bias · Efficient market hypothesis · Artificial neural networks · Deep learning

1 Introduction

Burton [1] suggests forecasts for exchange rate are pointless: "The theory holds that the market appears to adjust so quickly to information that no technique of selecting a portfolio - neither technical nor fundamental analysis - can consistently

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outperform a strategy of simply buying and holding a diversified group of assets". This idea is consistent with well-discussed efficient market hypothesis which constitutes one of the most fundamental finance theories during the last several decades. However, traders still use different tools for exchange-rate forecasting in the currency market to get a reliable decision-making technic. Several principal arguments revealed in the economic literature go against efficient market hypothesis in the foreign exchange market: (i) technical analysis is still profitable in spite the "market efficiency" [2; 3; 4], (ii) significant stake of the central bank interventions in 'making market inefficiency' [5; 6; 7], (iii) doubts about full market liquidity and rationality of exchange rate market participants [8] as well as a lack of confidence about any informational bias concerning all market participants [9; 10]. However, the rapid development of heuristic computational tools, enhancement of computers and computer equipment, and growth of electronic trading make room for a new form of efficient market challenge – technological bias. Assuming that technology is considered as 'scientific knowledge used in practical ways in industry' (Oxford Dictionary), we define technological bias in the market as a bias arising from enhancing trading tools and/or the trading environment based on development of the information technology. Technological bias has not motivated enough discussions among academics, despite its growing significance. It has worried other interested groups, mainly, market traders and state decision makers. Our contribution is in providing evidence against efficient market hypothesis, while displaying technological bias. Hence, the goal of the article is to disclose the upcoming technological challenge for the EMH in the foreign-exchange market with demonstration of cutting-edge computational tools as well as better performance in the prediction of foreign-exchange rates in comparison with the baseline time-series methods used in technical analysis for the last decades as well as random walk model.

The paper is organized as follows: Section 2 provides a brief review of the related literature. Section 3 describes the methodology. Section 4 presents results from our experiments and the discussion about technological bias. Section 5 concludes with some observations on our findings and identifies directions of future research.

2 Literature Review

2.1 Definition of EMH in the Exchange Rate Market

Efficient market hypothesis (EMH) is the concept widely accepted in the economic science which is based upon the belief in fully-disclosed market information and rational behavior of the market participants. It is mainly associated with the name of an American economist and Nobel laureate in Economics, Eugene Fama [11]. Despite a number of different efficiency market definitions, the definition provided by Fama is the most reasonable to use: "a market in which prices always "fully reflect" available information is called "efficient." According to the EMH, there are three degrees of market efficiency [12] – strong, semi-strong and weak. The weak form states that technical analysis is pointless and it is not more accurate than the famous random walk method. However, one arrives at the question, why are economists still doing predictions using technical analysis or why has the world economy faced one of the most severe financial crises in 2008 if the efficiency of financial markets is taken for granted in finance?

A recent survey found that around 90% of foreign exchange traders make their trading decisions based upon (to some degree) technical analysis, and that nearly 20% prefer it to other forms of information processing [13]. Interestingly, those similar results are found in the survey conducted by Taylor and Allen more than 20 years ago [14] which showed that at least 90% of chief foreign exchange dealers place some weight on technical analysis. However, the profitability of most popular approaches of technical analysis decreased significantly after mid-1990s which placed into question the efficiency of some of these tools. Hence, forecasting capacity of the technical analysis tools need to be tested as well as to potentiality improve the prediction accuracy with the computational solutions. Such computational solutions, like neural networks, must be investigated in accordance with one of the sub-goals of the article.

2.2 Technical Analysis Definition and Its Main Approaches

The issue about the predictability of exchange rates from the past and from current information is the fundamental theorem for modern trading technics with its implica-tions in investing. It constitutes one of the deepest controversies between academics and market participants. Despite that, technical analysis is still used by foreign ex-change professionals to predict movements in the currency market due to the belief that price fluctuations will reflect known patterns. Park and Irwin [15] propose a broad definition of technical analysis as a method of forecasting price movements using past prices, volume, and/or open interest. [16] explains technical analysis more specifically as a reflection of the idea that prices move in trends that are determined by the changing attitudes of investors toward a variety of economic, monetary, political, and psychological forces. The objective of technical analysis is to identify a trend reversal at a relatively early stage and ride that trend until the weight of the evidence shows or proves that the trend has reversed. [17] determines two main predictions used in technical analysis: (1) downtrends (uptrends) tend to reverse course with support of resistance levels, which can be defined ex ante and which are often round numbers; and (2) trends tend to be unusually rapid after the rates exceed support and resistance levels. Neely and Weller [18] explore two main types of the analysis to distinguish the trends from shorter-run volatility and to identify reversals: charting and mechanical (indicator) methods using charts, and technical analysts that seek to identify price patterns and market trends in financial markets and attempt to exploit those patterns. Mechanical methods are dependent upon functions of input and output exchange rates [18].

Recently, one can observe the downturn in the profitability of these approaches used in technical analysis. Hence, the heuristic methods have been proposed to be used which can capture not only the dynamics, but also the non-linearity of exchange-rates movements. Among them, neural networks claim to be a good forecasting tool. For example, Galeshchuk [19] demonstrates that multilayered perceptron with a single hidden layer can provide point estimates for the exchange rates with high enough accuracy for practical use. To verify the hypothesis, the instruments of artificial intelligence have been used to improve the prediction accuracy of technical analysis with comparison to the random walk model, which are subsequently explained in the next section.

3 Methodology

The data about exchange rates EUR/USD, GBP/USD, USD/JPY with daily step are collected from site http://www.global-view.com/forex-trading-tools/forex-history/index.html. Each time series contains 1304 observations (from January 1, 2010 to December 31, 2014). We use a training:testing split of 80:20. The first 1043 observations from 2010 to 2013 are used for training. The remaining 261 of the observations from 2014 are used to test the models. The experiments have been conducted to verify accuracy of random walk model, ARIMA, shallow neural network (multilayer perceptron) and deep neural networks.

The basic definition of a random walk model is a discrete stochastic process.

In Matlab documentation (Econometrics Toolbox > Model Selection > Specification Testing > vratiotest) the Random Walk model is described by the expression:

$$y(t) = c + y(t–1)+ u(t),$$

where y(t) is the value of the time series in the t moment of time, y(t-1) is the value of the time series in the previous moment of time (t-1), c – is a drift constant, e(t) is a random component.

Since this drift constant *c* helps to fix the trend of the time series, one of the ways to calculate it as an average value of the summary differences between current and previous values of the time series on its n steps: $c = \frac{\sum_{i=1}^{n} \Delta y(t)_i}{n}$, where $\Delta y(t)_i = y(t)_i - y(t-1)_i$ is the difference between current and previous values of the time series.

A standard MLP with one hidden layer of neurons is used as a prediction model. This kind of NNs has the advantage of being simple and provides good generalization properties [20]. The output value of three-layer perceptron can be formulated as:

$$y = F_3\left(\sum_{j=1}^{n} v_j h_j - b_3\right),$$

where n is the number of neurons in the hidden layer, v_j is the weight of the synapse from neuron j in the hidden layer to the output neuron, h_j is the output value of neuron j in the hidden layer, b_3 is the threshold of the output neuron and F_3 is the activation function of the output neuron.

The output value of neuron j in the hidden layer is given by:

$$h_j = F_2\left(\sum_{i=1}^{m} w_{ij}x_i - b_{2j}\right),$$

where w_{ij} are the weights from the input neurons to neuron j in the hidden layer, x_i are the input data and b_{2j} is the threshold of neuron j in the hidden layer. The logistic activation function $F(x) = 1/(1+e^{-x})$ is used for the neurons in the hidden layer and the output neuron.

Standard back-propagation training algorithm with fixed training speed is used for training [20]. Similar to Galeshchuk [21] the multilayer perceptron model 5-10-1 and one-step prediction mode are used for the experiments with daily exchange rates.

Deep networks are successfully used for unsupervised extraction of features of analyzed data on the pre-training phase [22; 23; 24] in order to improve an accuracy of the solved task. For the prediction of financial data, we use autoencoder at the pre-training stage in unsupervised way. The deep network uses the architecture and training strategies described in [25]. Specifically, we use l layers of hidden units separating the input layer from the output unit. Following the notation used in [25], we use b_j^i to denote the internal bias of the jth unit in the ith layer and W_{jk}^i to represent the weight of the connection to that unit from the kth unit in the $(i-1)$th layer. For an input vector x, the output of jth unit in the ith layer is computed as $h_j^i(x) = sigm(a_j^i)$, where $a_j^i = b_j^i + \sum_k W_{jk}^i h_k^{i-1}(x)$, and $sigm$ is the sigmoid function with $sigm(a) = (1+e^{-a})^{-1}$.

Table 1 below compares the mean absolute percentage error on the same data set for the deep and shallow neural network (DNN and MLP respectively), with those obtained using ARIMA (R package auto.arima from the library "forecast"), and random walk model (Random walk). Prediction error for period t is computed as $\left|\frac{\hat{x}_t - x_t}{x_t}\right| \times 100\%$. Average and maximum percentage error is computed based on the last n observations, where n is the number of test observations.

Table 1 Mean absolute percentage error (average and maximum) reported as a percentage

EXCHANGE RATE	METHOD	AVERAGE	MAXIMUM
EUR/USD	*MLP*	0.29	1.26
	DNN	0.15	0.91
	Random walk	2.40	5.20
	ARIMA	0.28	1.54
GBP/USD	*MLP*	0.25	1.39
	DNN	0.11	0.86
	Random walk	1.60	4.10
	ARIMA	0.25	1.35
USD/JPY	*MLP*	0.31	1.95
	DNN	0.21	1.12
	Random walk	2.80	4.30
	ARIMA	0.33	2.62

Concluding the results one can observe the success of shallow neural networks compared to random walk model with all exchange rate pairs. It also outperforms ARIMA in forecasting USD/JPY with daily rate. Japanese central bank tries to keep JPY lower and devaluated compared to USD for the export advantages. The fact that shallow neural networks produce slightly better prediction accuracy with JPY than the other tools can be explained by learning abilities of neural networks comparing to data mining instruments. In the other words, one can assume that neural networks while learning from the time series data can predict the market reactions when the particular market changes are observed. However, the prediction accuracy for the pair GBP/USD has nothing to do with technical analysis improvement taking into consideration absolute percentage error. Analyzing the results received with deep neural networks, they outperform in accuracy all of the other technics, including shallow neural networks and ARIMA.

4 Discussion about Technological Bias

Technical analysis does include different tools, however, innovative technics often appear with the development of a new generation of computers. From the previous section we can infer that the deep-learning technologies can do better than shallow neural networks, as well as ARIMA. Considering that ARIMA is one of the most commonly-used technics in creating the trading rules amongst market participants, we can make the conclusion that with the enhancement in the computational methods, along with software, technical analysis could be vastly improved. This can make some of the trades more successful with trading than others that are going against efficient market hypothesis.

In the same time, the nature of technological bias is in compliance with so-called adaptive market hypothesis proposed by A. Lo in 2006. Lo does not see markets as efficient, as stated by Fama, but believes that they are fiercely competitive. Because the "ecology" changes over time, people may make mistakes while adapting [26]. Old strategies become obsolete and new ones are called upon for solving problems. We consider technological shift as the change in market ecology. The degree of adaptation is often different for the participants, as a result, some of them will obtain more significant returns than others.

Within the relative literature, few papers discuss the application of neural networks and/or multi-agent systems for the foreign-currency market. A scarcity of literature where technological bias is analyzed from the point of influence on the market is observed. However, similar to technological bias, ignorance of technical analysis as a concentration of investigation has been observed in the economic literature until the 1990s. Technical improvement for scientific purposes is investigated by Amigoni, et al. [27]. In their mind, both computer science and artificial intelligence promise to radically transform conventional discovery environments by equipping users with a range of powerful computational tools. Another widely-used tool is multi-agent systems, which are systems of distributed artificial intelligence that are composed of several entities. These entities, called agents, are spatially distributed and interact together. Miller [28] presents a new series of market experiments that show that markets populated with standard robot traders are no longer efficient if time is a meaningful element, as it is in all asset markets. Manson [29] examines the use of evolutionary programming in agent-based modeling to implement the theory of bounded rationality. Evolutionary programming is also more commonly now being used to develop problem-solving strategies in accordance with bounded rationality [30].

Enhancement of trading rules and prediction tools are not the only expressions of technological bias. High-frequency traders may also contribute to volatility in financial markets. For example, sharp withdrawals from the market can occur, as it happened in the United States in May of 2010. The success of high-frequency trading strategies is explained by their ability to simultaneously process large volumes of information, something ordinary human traders cannot do [28]. The idea to impose a high-frequency trading tax is being discussed amongst politicians in developed countries.

5 Conclusion

With the development of a new generation of computers and new methods of forecasting concentrating on different fields of science such as biology, physics, etc., academics still are not paying much attention to technological shift. This shift will become more significant in the coming years. The traders with better programming environments, computers with faster CPUs, and more convenient locations will have an advantage with more accurate forecasting and receiving needed information from the market more quickly than their colleagues or competitors. This conclusion is reached after reviewing experiments described in the paper as well as analyzing the findings of economists who are actively searching for new approaches towards technical analysis. In the end, we believe this kind of bias plays a role in exchange rate market efficiency and deserves to be examined more in-depth in future research efforts.

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Web Browser-Based Forecasting of Economic Time-Series

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Abstract This paper presents the implementation of a time series forecasting algorithm, *jsEvRBF*, that uses genetic algorithm and neural nets in a way that can be run in must modern web browsers. Using browsers to run forecasting algorithms is a challenge, since language support and performance varies across implementations of the JavaScript virtual machine and vendor. However, their use will provide a boost in the number of platforms available for scientists. *jsEvRBF* is written in JavaScript, so that it can be easily delivered to and executed by any device containing a web-browser just accessing an URL. The experiments show the results yielded by the algorithm over a data set related to currencies exchange. Best results achieved can be effectively compared against previous results in literature, though robustness of the new algorithm has to be improved.

Keywords Time-series forecasting · Evolutionary computation · Radial Basis Function Neural Networks · Web-based programming · Volunteer computation

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1 Introduction

Nowadays, most programs executed by browsers are written in a language called JavaScript, developed in an attempt to do the Web more dynamic [6]. Current everyday massively-used web pages and web applications (including those related to social networks) exist thanks to this language. Its use has turned browsers into wider frameworks in which multi-platform applications can be run. JavaScript was standardized in 1997 by the European Computer Manufacturer's Association, or ECMA. According to the ECMA-262 standard, its real name is *ECMAScript*, but everyone calls the language *JavaScript* [4].

JavaScript can be described as a general-purpose, object-based, event-driven language. Adding JavaScript programs to web pages is simple: the code is inserted in the HTML code in plain text; then, it is downloaded by the browser that, finally, interprets and executes it. Due to the capabilities of JavaScript, in this work we propose the use of web browsers as agents able to download a web page containing a set of data, execute an evolutionary algorithm that evolves neural nets, and apply this neural nets to forecast an economic time-series. Using this approach, any device able to execute a web browser (from computers to smart TVs) can be potentially used to run our algorithm.

Both the problem being considered in this paper and the algorithm used to solve it were introduced in [7]. On the one hand, the problem consists on forecasting the values of the exchange rates between two currencies, for a four years period (data is weekly averaged). On the other hand, the algorithm (described in section 2) is a reduced version of *EvRBF* [7], an evolutionary algorithm that makes Radial Basis Function Neural Networks (RBFNN) to evolve.

RBFNN are well-known feed-forward neural nets with just one hidden and one output layers. They have been successfully used to solve classification, function approximation, and, as in this work, time-series forecasting problems [1, 5, 9]. Configuring an RBFNN in order to solve a task consists on: a) choosing the activation function for hidden neurons, b) choosing the number of hidden neurons, c) setting the parameters required by the activation functions (i.e., center and radius of the RBF), and d) setting the values for weights and bias. This last step can be easily computed once the rest of components have been established using the Least Mean Square method. *EvRBF* algorithm was designed to automatically search for the best configuration of an RBFNN that solves the problem being tackled, except for the activation function to be used that is always a Gaussian function.

In the herein, the implementation of *EvRBF* for web browsers (called *jsEvRBF*) has been compared to its original implementation as well as to the methods used by Sheta in [10], the work in which the data set used in this paper was introduced. Next sections describe: the algorithm (section 2); the problem to which the algorithm has been applied, as well as the experiments carried out and the results yielded (section 3), and conlusions and future lines (section 4).

2 The *jsEvRBF* Algorithm

jsEvRBF is an evolutionary algorithm written in JavaScript, so that it can be executed in web browsers. As in *EvRBF* [7], its predecessor, individuals are complete RBFNN, and special operators have been created to cross and mutate them. *jsEvRBF* is a generational algorithm, with a fixed number of individuals, that uses tournament selection and elitist replacement[1].

In order to implement both the RBFNN and the evolutionary algorithm, two JavaScript libraries: *jsRBFNN*[2] and *jsEO*[3], have been developed by our research group. *jsRBFNN* implements the nets and also the LMS training algorithm. *jsEO* [8] is a more complex framework that allows the generation of many kinds of evolutionary algorithms, making easier the task of creating new types of individuals and/or operators. Figure 1 graphically shows the dependencies between *jsEvRBF* and these libraries.

As a standard evolutionary algorithm, the skeleton of *jsEvRBF* is the following:

```
(1) Create, train and evaluate an initial population \
        of _p_ individuals.
(2) During _n_ generations do:
    (2.1) Select a subpopulation of _q_ individuals
    (2.2.) Create _q_ new individuals applying an operator \
            to each one in subpopulation
    (2.3) Train and evaluate the _q_ new individuals
    (2.4) Join and sort both old and new populations
    (2.5) Remove the _q_ worst individuals
(3) Send the forecasting done by the best individual \
    in last generation to the server
```

The fitness is computed using the inverse of the RMSE, so the greater the fitness, the better the individual.

With respect to the operators used in this algorithm:

- *XOver.* Takes two individuals as inputs and operates by randomly selecting a set of neurons from first individual and another set (probably of a different size) from the second one. After this, those sets are interchanged.
- *CenterMut.* Modifies a percentage of the centers of one individual setting them to random values in the range defined by the input dimension.
- *RadiusMut.* Quite similar to the precendent, this operator modifies a percentage of the radius of the neurons of one individual, choosing a new value in the same way the *CenterMut* operators does.

[1] The code can be downloaded or forked from http://bit.ly/jsEvRBF; its use is restricted under the terms of the Apache 2.0 license.

[2] http://bit.ly/jsRBFNN

[3] http://bit.ly/js-EO

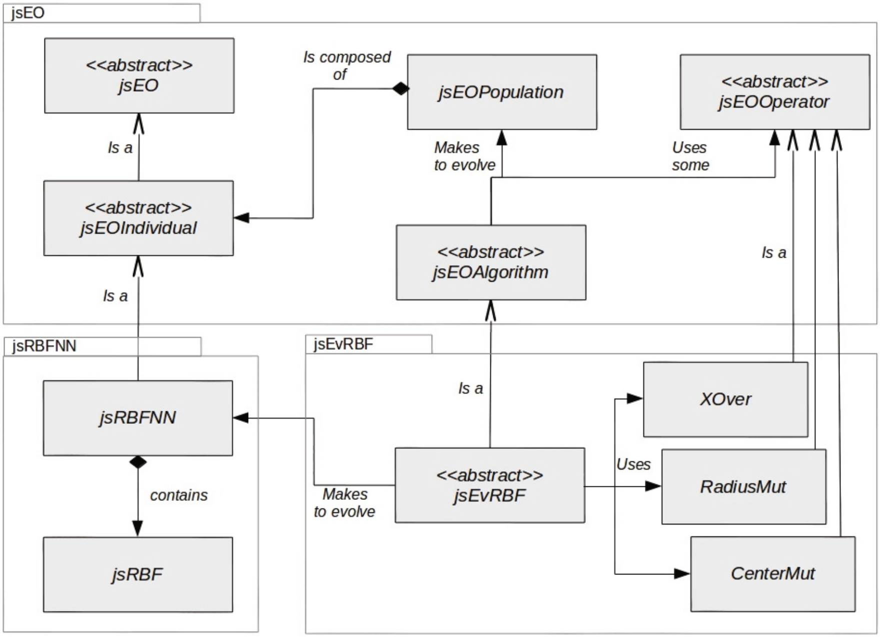

Fig. 1 Class diagram of the jsEvRBF algorithm, showing the way it depends on the jsEO general framework and the jsRBFNN library.

Finally, the following set of parameters has to be established in order to run the *jsEvRBF* algorithm:

- *trnSamples*: Set of samples to train the nets; it will be also used to select the centers of the RBF of the individuals composing the initial population.
- *valSamples*: Set of samples to compute fitness.
- *inputDimension*: Dimension of inputs.
- *numNeurons*: Number of neurons for individuals of the first population.
- *popSize*: Number of individuals per population.
- *numGenerations*: Number of generations for the evolutionary algorithm.
- *tournamentSize*: Number of individuals to consider when selecting one of them to reproduce.
- *replaceRate*: Rate of individuals to be replaced in every new generation.
- *xOverRate*: Determines the number of individuals to which xOver operators will be applied.
- *mutRate*: Determines the number of individuals to which mutator operators will be applied.
- *mutPower*: Determines the number of neurons that will be changed by mutator operators, when applied to an individual.

Next section shows the values used for these parameters along the execution of the experiments.

3 Experiments and Results

The *jsEvRBF* algorithm has been evaluated with the time-series used by Sheta and de Jong [10]. It is composed of 208 weekly averaged observations representing the exchange rates between Bristish pound and US dollar from 31 December 1979 to 26 December 1983[4]. This data set has been used in a similar way than Sheta and de Jong: only half the data (randomly chosen) has been used to train and validate the nets, but the generalization error has been computed over the whole data set.

Two experiments have been carried out using *jsEvRBF*. First one has been open to a wide community of users, so that many different devices, operating systems and web browsers have been used. On the other hand, the second experiment has been executed in a single computer, using a single web browser, so that we can focus in the forecasting process itself. In any case, participating in the experiment only required to connect to an URL; no special technical knowledge was necessary to run the algorithm since it was automatically executed once the web page was loaded.

Information about clients and the results they yielded were received by a server programed also in JavaScript (using *node.js*) and stored in a No-SQL database managed by *Mongo*; the language to query the database was JavaScript too.

3.1 First Experiment: Short Executions, Many Browsers

The first experiment carried out was designed to test whether the kind of computation described by *jsEvRBF* could be effectively executed in different platforms. To do this, a "call for volunteer computation" in the form of messages published in Twitter and Facebook was done. Any of these two accounts were followed by about 500 people.

Table 1 shows the value specified for every parameter. They differ from the ones used in previous work [7] due to the lack of power of low-quality, old smartphones. An initial test showed that browsers running in that kind of devices usually blocked the execution of the algorithm; this led us to configure the experiment paying more attention to the algorithm's ability to be executed in any device more than in its ability to perform the best forecasting.

This experiment was available for users from 8-Jan-2016 to 18-Jan-2016. Every time a user accessed to the URL, 15 independent executions of the algorithm were sequentially run in his/her web client. The user could easily stop these executions

[4] The source of the information, thanks to the work done by Prof. Werner Antweiler from the University of British Columbia, Vancouver, Canada, is available from http://pacific.commerce.ubc.ca/xr/data.html.

Table 1 Values for parameters in the first experiment. The number of samples (*trnSamples* and *valSamples*) are approximated as they were randomly chosen in every execution: approximately 45% of data were used for training, and 5% for validation.

Parameter	Value	Parameter	Value
trnSamples	≈ 90	*valSamples*	≈ 15
inputDimension	1	*numNeurons*	7
popSize	10	*numGenerations*	10
tournamentSize	2	*replaceRate*	0.8
xOverRate	*Not used*	*mutRate*	1.0
mutPower	0.5	*Executions per page load*	15

Table 2 First experiment: comparison of MSE yielded by the *jsEvRBF* algorithm and the ones cited in [7]. Errors have computed over the full set of data.

Method	Average MSE	Best MSE
EvRBF	$6 \times 10^{-4} \pm 2 \times 10^{-4}$	4×10^{-4}
MSE-GA	9×10^{-4}	N/A
MSE-LSE	12×10^{-4}	N/A
jsEvRBF	$2 \times 10^{-2} \pm 5 \times 10^{0}$	6^{-4}

at any moment. After every execution, results were sent to our server to store a description of the web browser, and a set of error values including MSE among others.

The analysis of the results showed that a total of 165 different access were made to the page during the cited period, resulting in 2304 executions, i.e., 13.9 executions in average per client. Up to 25 different versions of browser were detected, more than a half were Chrome browsers (58.79%), followed by Safari (26.06%) and Firefox(15.15%). Unfortunately, only 80% of the solutions were valid, since in some executions performed by Chrome and Safari browsers (i.e., those based on AppleWebKit) a NaN error appeared when training the nets. This can be considered one of our first conclusions since, even having used standard javaScript code, there exist differences in the way browsers compile it.

With respect to forecasting, Table 2 shows the MSE of the algorithm and compares with results from previous papers by Rivas [7] and Sheta [10]. The average MSE of *jsEvRBF* with respect to the rest of methods is quite high (2 orders of magnitude). This is also due to the previously cited non-valid solutions found by AppleWebKit-based browsers: once the training fails, nets can't evolve and no better solutions than those found in initial generations are built. As Table 2 shows, the best solution found by the entire set of browsers is 6×10^{-4}, similar to the average error found by the original *EvRBF* algorithm. This is true not only for the best solution: the average MSE of the best 50 solutions is still 6×10^{-4}, while the average MSE of the best 500 solutions is equal to that value for the MSE-LSE algorithm. In any case, the algorithm, as it is currently implemented, shows a lack of robustness that needs to be tackled and fixed.

Table 3 Configuration of parameters for the second experiment. As in the first one, the number of samples (*trnSamples* and *valSamples*) is still approximated since they were randomly chosen in every execution. Values that differ from experiment 1 have been highlighted in **bold**

Parameter	Value	Parameter	Value
trnSamples	≈ 90	*valSamples*	≈ 15
inputDimension	1	*numNeurons*	**10**
popSize	**15**	*numGenerations*	10
tournamentSize	**3**	*replaceRate*	**0.2**
xOverRate	**0.2**	*mutRate*	**0.8**
mutPower	0.5	*Executions per page load*	**1**

Table 4 Second experiment: comparison of MSE yielded by the *jsEvRBF* algorithm and the ones cited in [7]. Errors have computed over the full set of data, having executing the algorithm 10 times.

Method	Average MSE	Best MSE
EvRBF	$6 \times 10^{-4} \pm 2 \times 10^{-4}$	$4 \times 10^{-4} \pm 2 \times 10^{-4}$
jsEvRBF	$8 \times 10^{-4} \pm 2 \times 10^{-7}$	6×10^{-4}
MSE-GA	9×10^{-4}	N/A
MSE-LSE	12×10^{-4}	N/A

3.2 Second Experiment: Long Executions, One Browser

Once detected the error introduced by AppleWebKit-based browsers, a second experiment was carried out in a more controlled environment, and with a configuration similar to the original experiments in [7]. These new executions were run using a Firefox 44 browser, and configured as showed in Table 3.

The results for this second experiment, averaged over 10 executions of the algorithm, were clearly better than those yielded in first one, as can be seen in Table 4. Although the original *EvRBF* algorithm still yields the best result ($6 \times 10^{-4} \pm 2 \times 10^{-4}$), *jsEvRBF* can be compared in this occasion with it ($8 \times 10^{-4} \pm 2 \times 10^{-7}$), and is lower than MSE-GA (9×10^{-4}) and MSE-LSE (12×10^{-4}). Further study must be done to determine the causes that makes the new algorithm being not so accurate as the original one, but probably the absence of some of the operators not yet programmed could be the reason.

4 Conclusions

Web-browsers have been proved to be a good alternative to achieve distributing computation, minimizing the effort needed to ensure cross-platform compatibility and easiness of use. To show it, we have introduced the *jsEvRBF* algorithm; written in JavaScript, this algorithm can be executed in web-browsers when users access to a specified URL. The web page downloaded by the browser contains the code of this evolutionary algorithm, able to build, train and evolve RBFNN used to perform time-series forecasting over a set of data related to currency exchange.

The experiments carried out show that the approach is valid, although some research must still be done in order to determine the reasons that make AppleWebKit-based browsers (mainly Chrome and Safari) not work properly.

Future work includes the use of the algorithm in an *island model* framework in which good individuals be distributed to the clients running the algorithm.

Acknowledgements This work has been supported in part by: Ministerio de Ministerio español de Economía y Competitividad under (preselected as granted) project TIN2014-56494-C4-3-P (UGR-EPHEMECH), CEI2015-MP-V17 of the Microprojects program 2015 from CEI BioTIC Granada, PROY-PP2015-06 (Plan Propio 2015 UGR), and PRY142/14 (Este proyecto con num. de referencia: PRY142/14 ha sido financiado ntegramente por la Fundación Pública Andaluza Centro de Estudios Andaluces en la IX Convocatoria de Proyectos de Investigación)[5].

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[5] The description in Spanish is mandatory.

Cross-Entropy Based Ensemble Classifiers

Giovanni Lafratta

Abstract Multiple classification rules are simultaneously identified by applying the Cross-Entropy method to the maximization of accuracy measures in a supervised learning context. Optimal ensembles of rules are searched through stochastic traversals of the rule space. Each rule contributes to classify a given instance when the observed attribute values belong to specific subsets of the corresponding attribute domains. Classifications of the various rules are combined applying majority voting schemes. The performance of the proposed algorithm has been tested on some data sets from the UCI repository.

Keywords Big data analytics · Classification · Stochastic data mining · Supervised machine learning

1 Introduction

The Cross-Entropy method raises in the context of rare-event probability estimation [4]: importance sampling is exploited to define a sequence of estimators, each one based on a sample drawn from a parametric distribution under which the event hopefully becomes more and more probable than under the distribution of interest. In this way, additional estimators having a variance less than that of the previous ones are added to the sequence. New estimators are selected by minimizing the Kullback-Leibler cross-entropy between their importance sampling distributions and the theoretical one under which the estimation variance would be zero [6]. Soon the method was recognized as closely related to the optimization of continuous or discrete functions [5]. In fact, optimizing a function can be seen as the problem of estimating the

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probability of the event represented by the function assuming a value over a given extreme threshold, an event that can be typically interpreted as rare.

In this paper, we propose to apply the Cross-Entropy method to the maximization of classification accuracy measures. Optimality is defined in terms of ensembles of classification rules [3], each rule applying to a given instance when the observed attribute values belong to specific subsets of the corresponding attribute domains. The method builds candidate ensembles simultaneously, in the sense that rules are not added to a candidate ensemble as a function of the rules already in the ensemble under construction. As a consequence, the algorithm scales well in both on-premises and cloud distributed computing environments.

This paper is organized as follows. In Sect. 2 we define the space of classification rules which will be searched for the optimal ensemble. Section 3 describes the steps of the proposed algorithm, whose performance is illustrated in Sect. 4 by investigating its application to the analysis of some data sets from the UCI Repository [2]. Finally, Sect. 5 contains some concluding remarks.

2 Ensembles of Classification Rules

Let us assume that instances from a given space $\mathcal{X}$ must be classified into a set $\mathcal{Y}$ of labels. If m input attributes are taken into account, and if attribute $j \in \{1, \ldots, m\}$ has finite domain D_j, then $\mathcal{X}$ can be represented as the Cartesian product $D_1 \times \cdots \times D_m$. A *classification rule* R is a pair $(\mathcal{C}, y)$, where $\mathcal{C}$ is a proper subset of $\mathcal{X}$ and $y \in \mathcal{Y}$. Given an instance $\mathbf{x} \in \mathcal{X}$, the rule will classify $\mathbf{x}$ as y if and only if $\mathbf{x} \in \mathcal{C}$. When this is the case, rule R is said to *vote to classify* $\mathbf{x}$ as y. If an ensemble of rules $R_k = (\mathcal{C}_k, y_k)$ is available, with k in a finite set $\mathcal{K}$, then unlabeled instances can be classified by performing majority vote procedures. If weight $w_k > 0$ is assigned to rule R_k, $k \in \mathcal{K}$, then the classification of a given instance $\mathbf{x}$, say $y(\mathbf{x})$, can be defined as satisfying

$$y(\mathbf{x}) = \arg\max_{y \in \mathcal{Y}} \sum_{k \in \mathcal{K} : \mathbf{x} \in \mathcal{C}_k \wedge y = y_k} w_k,$$

where ties are eventually resolved by selecting one of the maximizing arguments at random.

3 Cross-Entropy Algorithm for Accuracy Maximization

The Cross-Entropy method can be exploited to search the rule space and create ensembles, among those having a fixed size n, which correspond to maximal accuracy. The algorithm iteratively executes two main steps. The first one, the *sampling step*, is responsible for generating diverse candidate ensembles of classification rules. In this step, ensembles are interpreted as points of a sample drawn from a distribution defined on the Cartesian product of n replicates of the rule space, each replicate being independent from the others. Sampling a rule $R_k = (\mathcal{C}_k, y_k)$ from the k-th replicated space is executed as follows. Firstly, a finite discrete distribution $p_{\mathcal{Y},k}$ is defined on the label domain $\mathcal{Y}$ and sampled to obtain label y_k. Secondly, the rule condition $\mathcal{C}_k$ must be sampled too. This is equivalent to select at random, for each input attribute j, a subset $C_{j,k}$ of domain D_j, and hence define $\mathcal{C}_k = C_{1,k} \times \cdots \times C_{m,k}$: to obtain such result, a Bernoulli distribution, say $p_{j,i,k}$, is assigned to each value i in the attribute domain D_j: sampling $x_{j,i,k}$ from $p_{j,i,k}$ enable us to set $i \in C_{j,k}$ if and only if $x_{j,i,k} = 1$.

At first iteration, each rule has the same probability to be included in a sample point (ensemble); this is accomplished by defining a balanced Bernoulli distribution for each value in each input attribute domain, and a uniform finite discrete distribution on the label domain $\mathcal{Y}$. The *update step* aims to modify the distribution from which the samples will be obtained in the next iteration, in order to improve the probability of sampling better performing rules. Let us represent the sampled ensembles in the current iteration as $\mathcal{E}_1, \ldots, \mathcal{E}_N$. The corresponding accuracies, say $a_1, \ldots, a_N$, are computed and sorted in increasing order, $a_{(1)} \leq \cdots \leq a_{(N)}$. In this way, the ensembles which guarantee the best performances can be identified as those whose accuracies occupy the last positions in the ordering. The Cross-Entropy method refers to such sample points as the *elite samples*. A way to define them exactly is as follows. A parameter ρ is set to a value in the interval $[.01, .1]$ and all those samples occupying a position greater than or equal to $\eta = \lceil (1 - \rho) N \rceil$ are defined as elite ones. Given the elite ensembles, $\mathcal{E}_{(\eta)}, \ldots, \mathcal{E}_{(N)}$, the joint distribution from which the ensembles will be sampled in the next iteration is updated by estimating its parameters using the elite ensembles only. Since they correspond to better accuracies, this updating mechanism guarantees that rules having better performances will be included in subsequent samples with greater probabilities. The algorithm stops if the accuracy *level* which defines the elite samples points, i.e. $a_{(\eta)}$, remains unchanged for a predefined number of consecutive iterations.

4 Empirical Evidence

The proposed inducer has been tested against the *Congressional Voting Records* (CVR) and *Nursery* UCI data sets, using the training set sizes described in Table 1. Let m represent one of those sizes for a given data set; a corresponding experiment has been designed to estimate classification accuracies following [1]: the data set has been randomly partitioned into two subsets, the first, referred to as the *universe*, has size $2m$ and is the one from which we draw 10 samples, having size m, which represent the training sets passed to the inducer; the second one, referred to as the *test* subset, is intended to evaluate the accuracy of the induced classifiers. All ensembles were formed by 100 classification rules, with uniform weights equal to 1. Further parameters of the Cross-Entropy algorithm were set as follows: at each iteration, a sample of $N = 1000$ ensembles was drawn and the elite ensembles have been

Table 1 Data sets under study and corresponding training set sizes

Data set	Data set size	Attributes	Classes	Training set sizes
CVR	435	16	2	50, 100, 150, 200
Nursery	12960	8	5	500, 1000, 2000, 3000

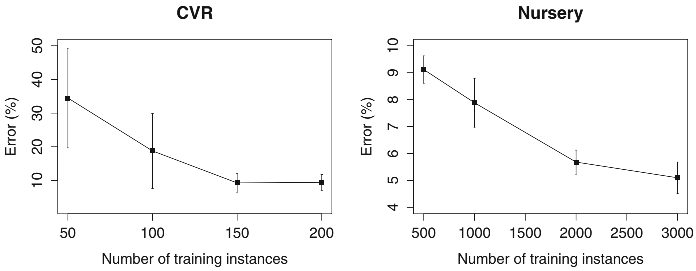

Fig. 1 Learning curves of 100 classification rules for data sets CVR and Nursery

identified by setting $\rho = .1$; finally, the stopping criterion came into effect if the *level* did not change for 10 iterations. Results for data sets *CVR* and *Nursery* are shown in Fig. 1. The points represents the mean error rate of the 10 training runs, while the error bars show one standard deviation of the estimated error. It can be noted that, for data set *CVR*, stabilization occurs at about 150 instances, while for data set *Nursery* it occurs approximately at 2000 instances.

5 Conclusions

In this paper, the Cross-Entropy method has been exploited to induce ensembles of classification rules. Observed accuracies deserve further investigations in order to detect possible enhancements based on other than uniform majority voting schemes. Given that a by-product of the algorithm is the estimated distribution of the target attribute conditional to each rule, the votes can be easily modulated by taking into account the variability of such distributions: for example, one can assign greater weights to rules whose corresponding distributions are less heterogeneous.

We also expect to devote future researches to study how the accuracy relates to the size of the induced ensembles, especially when applied to high dimensional data sets.

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How Does Fairness Relate to Economic Decision-Making? An Experimental Investigation of Pro-Social Behavior

Edgardo Bucciarelli and Tony E. Persico

Abstract The role of fairness in economic decisions is currently at the center of numerous investigations highlighting pro-social preferences. In this paper, we focus on Amartya K. Sen's concept of meta-ranking to study sets of preference orderings according to some fair principle. On the one hand, we propose a model based on a meta-utility function to explore different structures of preferences. On the other hand, we run an experimental economic game to test the role of meta-ranking, analyzing the results with a tensor-based method. The meta-ranking confirms the evidence of pro-social behavior in economic decision-making. This is consistent with the findings of the recent economic literature.

Keywords Meta-ranking · Experimental economic game · Behavioral economics · Data-mining · Socially framed context

1 Introduction

There is plenty of experimental evidence for pro-social behavior in economic decision-making. While some of the observed pro-social behaviors may be solely due to experimenter's demand effect (Hawthorne effect), we study neutral payoffs in order not to interfere in the composition of the structures of individuals' preferences. Our evidence suggests that the role of emotions, values and decisions to cooperate with others or to compete with them are important components of the interactions that occur between and among economic agents. In fact, after having analyzed the results of real interactions between experimental subjects we have

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been able to highlight the role of shared social values. The key contribution of heterodox theories in this field is fundamental. Among many contributions, we recall the role of fairness motives over selfishness by Amartya K. Sen [17] and the idea of bounded rationality by Herbert A. Simon [19]. Furthermore, we emphasize the importance of the intersection of three core concepts presented by Simon:

1. the need for empiricism in microeconomic models [19];
2. the normative character of decisions [18];
3. the evolutionary relationship between agents and economic scenarios [20].

Among these concepts, empiricism emerges as a unifying theme of several interdisciplinary approaches to the study of economic decision-making. Therefore, we acknowledge that empirical methods and data sources are complements, not substitutes [6] and they jointly generate real-world data. By real-world data we refer not only to the standard empirical evidence (*e.g.* datasets and stylized facts), but also qualitative and quantitative evidence regarding behavioral and cognitive data gathered from lab and field experiments as well as exploratory research utilizing inductive analyses [22, 23, 13]. The purpose of using experiments for progress economic studies lies in better understanding of *"motivated human interactive decision behavior in social contexts governed by explicit or implicit rules"* [21]. Thus, the purpose of experimental economics is, as much as feasible, to reproduce the conditions of ordinary and everyday experience. In this regard, experimental economists demonstrate, by using empirical methods, that there are implicit rules followed by economic agents that have not been adequately considered or accounted by standard economic theory. Significantly, experimental economists have challenged traditional notions of rationality as held by neoclassical economists wondering why, for instance, *"people in certain contexts choose outcomes yielding the smaller of rewards"* [21] rather than concluding that this is irrational.
Experimental economics has recently discussed ethical issues and economic behavior, in particular the role of fairness, providing a sound empirical basis for arguing that greater equity is critical for greater efficiency [12]. The standard economics framework has long ignored the social setting within which economic behavior emerges and takes place. In dealing with other individuals, several studies analyze why individuals might choose to behave fairly even with not in line with mere self-interest. One of the major criticisms leveled at the standard economics is to admit other motivations beyond self-interest [15, 16, 17]. In order to admit these motivations, we need to pursue a twofold objective. First, to overcome the methodological individualism as the exclusive approach to the study of economic behavior and, second, to deal with normative and social issues. The experimental economics techniques allow achieving this dual objective [11] shifting the focus of the economic studies on the human being. In line with this strand of literature, our work addresses the relevance of value judgments to the frame of economic decisions and is motivated by the psychological evidence on social comparison and loss aversion. Two ground-breaking papers appeared in the Quarterly Journal of Economics [7, 4] became seminal both to the research stream that is concerned with experimental games on social preferences more directly than

existing experiments and to any further developments in this field. In short, we can assert that Fehr's & Schmidt's model (FS) focuses on self-centered inequity aversion, recognizing the existence of different types of preferences and considering these as a result of "environmental" conditions of the tests. Charness's and Rabin's model (CR) allows different pro-social choices in order to evaluate different motivations expressed as different structures of preference. The main pro-social behaviors identified by the model are: competitive preferences, when an individual maximizes her own payoff in spite of other's payoff; difference aversion, when the difference among payoffs is minimized; reciprocity, when the other's payoff is maximized; social welfare, when the total of payoffs is maximized (for a survey see also [14]).

2 A Meta-Utility Model

Consistent with the emerging literature, we build a model able to take into account the utility of the payoff as well as the intrinsic value of different structures of preference. In doing this, we apply a methodology with the following characteristics: i) the model detects only the results deriving from interpersonal interactions; ii) the data analysis considers the single individual's response set as a single entity. More specifically, our model builds on the CR model: 1) CR model identifies different structures of preferences regarding six parameters, three of which are binaries; to this aim, we use a single parameter, making less complex the subsequent data mining analysis; 2) the use of a single parameter permits to build our function of repartition as in FS model; 3) CR model simulates subject's responses to observe the reaction of another subject; this may raise some problems with regard to falsification: simulated behaviors can be extraneous to the subjects under investigation; in order to overcome this potentially critical issue, our model includes only real responses from real experimental subjects; 4) previous models use only partially the information coming from options not-selected by the experimental subjects; differently, we use also this information to consider the role of meta-ranking of different structures of preferences.

The utility function used in the model assumes the form:

$$U_2 = f\,(s_2, s_1, p) \tag{1}$$

Under the following hypothesis,

$0 \leq p \leq 1$

$U(s_2) = s_2$

$(s_1 - s_2) > 0$

the utility of the experimental subject 2 (U_2) depends on both the payoffs of the two subjects (s_2, s_1) and the value acknowledged to subject 1's payoff including different structures of preferences expressed with a parameter (p).

The (1) has some properties: i) it allows to create a partition function for the parameter p; ii) in case of equal distribution of the payoffs, the utility is independent from the value of the parameter p; iii) it has a concave trend; iv) it identifies the conditions to change the structure of preference.

We can hypothesize that the actual choice of a type of preference has a particular value for the individuals. Therefore, we show the role of different structures of preferences searching for an empirical substantiation of meta-ranking and pro-social behavior [16, 17]. In this case, we can introduce a meta-utility function as follow:

$$U_{m2} = max\ (0,\ \bar{U}_2 - U_2) \quad (2)$$

Where $\bar{U}_2$ indicates the subject 2's utility related to the payoffs excluded by the first subject. We can now define U_2^* as the sum of the main utility U_M according to (1) and meta-utility U_m according to (2) weighted with a parameter (r) which indicates the importance given to meta-utility by the subject 2:

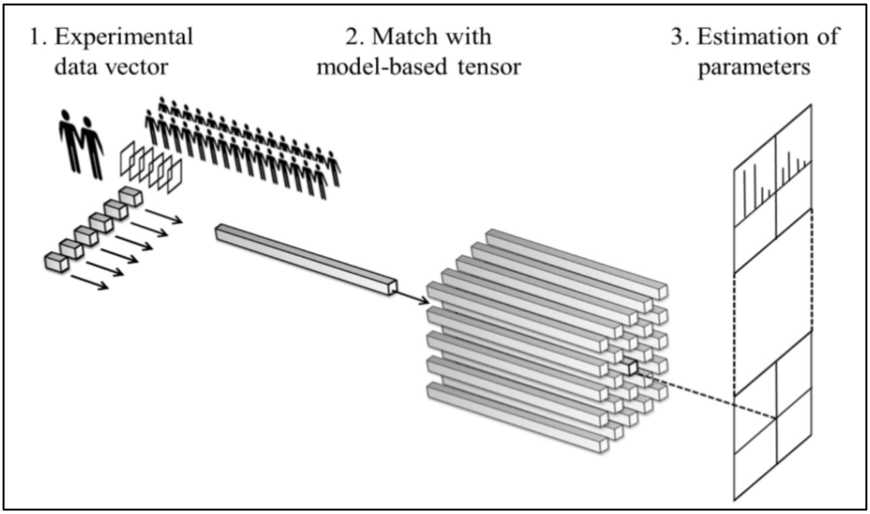
$$U_2^* = U_{M2} + r\ U_{m2} \quad (3)$$

3 The Experimental Design

The model based on meta-utility function (see Section 2) was tested through an experiment conducted in three different high public schools located in Pescara (Italy) from 23 to 27 March 2015. The students who randomly participated in the experimental sessions were 314, belonging to five fifth classes for each of the three schools (grammar, scientific and technical). According to Charness *et al.* [3], we run an extra-lab classroom experiment of the type paper-and-pencil to involve more student interaction and avoid estrangements from the community in which students live during the school-year [1]. The extra-labs can be defined "physically-oriented versions" of lab experiments with a more robust external validity. After having made arrangements with their respective Deans, we entered in five casual classes for each school to guarantee the randomization of the scholar population. Among the tests used in literature, we run an experimental economic game, the ultimatum game experiment, proposed by Güth *et al.* [9] to explore concepts such as reciprocity and cooperation since its combination of strategic interaction and fairness concerns. The test is composed of two phases each of which is made up of twenty repeated experimental questions. Thus, each of the two phases considers a couple of subjects who do not know each other and have to interact sequentially (subject 1 makes the first choice, and subject 2 makes the second one). In the first phase there are the first moves, while in the second one roles are inverted with different casual couples of subjects. The types of payoffs are summarized in Table 1 and the entire treatment submitted to the experimental pool is in the Appendix. The tests are anonymous (stranger condition) to avoid reputation effects (reputational condition) so that to allow interactions to take place among anonymous strangers in a socially framed context. Finally, we use a random-choice payment method by drawing a prize consisting of € 15,00 for one student in each classroom (random winner reward).

4 Results

Even if it is possible to regard and interpret the subjects' results as one by one, we focus on the entirety of subjects' responses as a single entity to investigate. Hence, we treat the obtained experimental results as if they were vectors rather than as individual results and we perform a data-mining analysis using a tensor-based method (see Figure 1).



Source: our elaboration.

Fig. 1 The proposed methodology of analysis.

Table 1 Analysis of the experimental results.

analysis	type of payoffs proposed					questions analyzed	F^* (%)	F (%)
	the same SW & different equity (questions 1-5)	SW & equity inversely proportional (questions 6-8)	altruistic (sacrifice) propensity (questions 9-10)	greater SW & inequality vs equity & the same SW (questions 11-14)	greater SW & inequality vs equity & minor SW (questions 16-20)			
1	√	√	√	√	-	14	85,2	59,7
2	√	√	√	√	√	19	69,8	41,1
3	-	-	-	-	√	5	77,7	74,6

Source: our elaboration. See the Appendix to distinguish the reference numbers of the questions. Legend: SW stands for social welfare.

Given two vectors, the first one has discrete and progressive h values of the parameter p, the second vector has k values of the parameter r. Following the instructions given in Microsoft SQL, we use an algorithm to solve the 20 n questions (submitted to the experimental subjects) applying the function (3) with all the combination of the possible values of parameters. The result is a model-based order three-tensor T^{hkn}. We evaluate the efficacy of the model and the effectiveness of meta-utility analyzing the matches between experimental data and model-based tensor. We carry out three different analyses of our experimental results in order to extract the largest possible number of useful information by taking into account different ranges of neutral payoffs (see Table 1). The proposed model explains a percentage of vectors of experimental responses from 70 to 85% (shown in Table 1 with F^*). Excluding the effectiveness of meta-ranking, the percentage of vectors of responses explained by the model (F) significantly decreases. Accordingly, the meta-utility makes explicable almost a quarter of the answers otherwise unexplainable.

In the following, we summarize some of the implications of our approach that can be generalized. Subjects transmit information of normative values through their choices; normative values can be synthesized with structures of preferences; subjects elaborate a pro-social behavior as preferable *state of the world*. These implications can be usefully used in social network analysis, social relations modeling, and social Artificial Intelligence (AI) [8, 5]. The external validity of our experiment can be analyzed in terms of proximal similarity [3]. We randomly selected classrooms within three different schools involving different subjects, different vocations and aptitudes, two located in the center of the city (Pescara, Italy) and one in its suburbs. For these reasons, we believe that the results can be sufficiently generalized. The statistic sample is composed by students attending the last year of the high schools considered who participate voluntarily within a socially framed context [10, 3].

5 Concluding Remarks

The role of fairness in determining economic decision-making is explored in this paper along with the motivation for extending the line of the experimental methodology focused on pro-social behavior. Moving away from the standard emphasis on purely selfish motives, we investigate the role played by pro-social preferences on individual decisions by proposing a model based on the concept of meta-ranking of preferences structure. In particular, we introduce a meta-utility function capable to explore the role of different structures of preferences in the construction of pro-social behavior. We perform an extra-lab classroom experiment running an experimental economic game (the ultimatum game experiment) to test the model proposed. The experiment allows experimental subjects to choose between different payoffs options not only according with the individual payoff. We find the results consistent with the idea that individuals' decisions are affected by the reference social group in which they operate. Furthermore, the experimental results show the importance of the meta-utility function since it permits to explain almost the 25% of answers collected during the experimental sessions, otherwise unexplainable. In our view, the proposed applied methodology of analysis appears a useful tool to guarantee a correct representation of the experimental data gathered within a socially framed context. Finally, these results call to mind that the interaction between the distribution of preferences and the current economic environment claims more attention in future research, especially to explore the impact of social preferences on decisions made outside of the lab. This is particularly true for the investigation of the role of other-regarding behavior in a particular social setting, which can only be introduced in experimental economics by abandoning some degree of abstraction.

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Appendix

In the following, we show the treatment submitted to the experimental subjects including all the payoffs proposed in the *ultimatum game experiment* run. The payoff A (*e.g.* A: 100) is the first subject's payoff, while the payoff B (*e.g.* B: 10) is the second subject's payoff. The first subject is requested to choose between option 1 or 2 for each question. Similarly, the second subject is requested to choose between the option selected by the fist subject and the ultimatum option.

question	option 1	option 2	ultimatum option
1	A: 100; B: 10	A: 60; B: 50	A: 0; B: 0
2	A: 100; B: 10	A: 80; B: 30	A: 0; B; 0
3	A: 100; B: 10	A: 70; B: 40	A: 0; B: 0
4	A: 80; B: 30	A: 70; B: 40	A: 0; B: 0
5	A: 70; B: 40	A: 55; B: 55	A: 0; B: 0
6	A: 110; B: 30	A: 70; B: 50	A: 0; B: 0
7	A: 140; B: 20	A: 70; B: 50	A: 0; B: 0
8	A: 180; B: 40	A: 80; B: 80	A: 0; B: 30
9	A: 140; B: 80	A: 150; B: 70	A: 180; B: 60
10	A: 40; B: 75	A: 35; B: 85	A: 80; B: 65
11	A: 80; B: 12	A: 50; B: 50	A: 0; B: 0
12	A: 100; B: 10	A: 50; B: 50	A: 0; B: 0
13	A: 100; B:5	A: 50; B: 50	A: 0; B: 0
14	A: 100; B: 10	A: 80; B: 12	A: 0; B: 0
15	A: 100; B: 10	A: 80; B: 8	A: 0; B: 0
16	A: 110; B: 30	A: 70; B: 50	A: 0; B: 0
17	A: 140; B: 20	A: 70; B: 50	A: 0; B: 0
18	A: 180; B: 40	A: 80; B: 80	A: 0; B: 0
19	A: 180; B: 40	A: 80; B: 80	A: 0; B: 20
20	A: 180; B: 40	A: 80; B: 80	A: 0; B: 40

What Network Analysis Can Teach Us About Chinese Economic Structure

Vittorio Carlei, Alina Castagna, Leila Chentouf and Donatella Furia

Abstract The reforms undertaken or expected by Chinese policymakers are likely to cause significant stress on the economy. In order to understand the implications for the economic system and its capacity to resist these shocks successfully (resilience), we carried out a spatial network analysis that helped to identify intersectoral interdependencies which could affect the behavior of the Chinese economy in reaction to exogenous (policy) shocks. The analysis starts from estimating the sectoral specialization of 287 municipalities across 14 industries using occupational employment shares. Secondly, the analysis identifies sectoral interdependencies across these sectors using a network based approach.

Keywords Network analysis · Chinese labour market · Minimum spanning tree

1 Introduction

It is well-known that over the last three decades, China, one of the key players in Asia, has grown at an average annual rate exceeding 9 percent. However, China's development model has recently faced some constraints that could affect its sustainability. Taking into account this risk, public authorities have to face judiciously the current challenge. With this framework in mind, the configuration of the economic structure becomes crucial in order to define intersectoral interdependencies.We decided to analyse it in spatial framework through a network-based approach. Our objective is to observe how the properties of a spatial network could affect the behavior of the Chinese economic system and the processes occurring within them. From this, we identified economic sectors which play the role of spatial pivots and whose interplay becomes crucial for the stability of the economic structure following node

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characteristics spreading external solicitations. Put simply, the sectors represented the nodes of the network while the links between them were represented by their relative industrial relevance. The more the relative industrial relevance of one sector is similar to that of another sector in different city, the closer these two sectors will be in the network. It is important to be clear that the network is configurated through the Minimum Spanning Tree (MST). This means that we present the path after a pruning process of a connected graph. Indeed, after that, we got a network configuration which indicated the most likely path of propagation of an external solicitation. Based on Mantegna's research (1999), we will provide a methodology to find the hierarchical structure of a whole economy by identifying economic sectors which act as a hub. Our basic assumption is that the morphology of the resources allocation (employees) in each sector is a proxy of the local production system and therefore of regional complexity. This micro-founded point of view allows us to associate with each city a pattern whose morphology is described in terms of allocation of resources employed in the sectors [8].

To do this we have structured our paper as follows. We will start with the empirical analysis where we specify the theoretical background that inspired our work. In the second part, we will examine the case of China in order to highlight the current challenge that the public authorities have to face. Finally, we will define, in the framework of the network based approach, industrial sectors which could affect the evolution of the Chinese economic structure following their level of connectivity in the case of an external stress.

2 A Theoretical Background

Recently, the presence of interconnections between firms and sectors and their roles as a potential mechanism of propagation of shocks through the economy was analyzed by [1]. They provide a general mathematical framework in order to analyze the extent of propagations of shocks and how the role of sectors, in aggregate fluctuations, depend on the structure of interactions between them.

As regards us, we focus our attention on scale free networks[1] because of the behavior of such a complex network as a reaction to external solicitations seems to act in predictable ways when an exogenous shock puts pressure on them. In other words, networks containing hubs, or nodes with a large number of links, seem to be extremely vulnerable to coordinated attacks because of their inhomogeneous topology [5].

This work is particularly inspired by [16]. He finds a topological arrangement of equities in financial markets by using a correlation based model in describing the network's shape and topology through a *Minimum Spanning Tree (MST)*. The main

[1] Evocative issues on the empirical evidence of scale free networks are those regarding the connection of social and communication patterns (see [2, 4, 6] or in other fields such as Biology [12, 15]).

goal of this procedure is that the price time series in a financial market reflects information about the economic sector of the activity of a company [7] grouping them in clusters of nodes over the network.

Starting from these interesting studies we will provide a methodology to identify a hierarchical structure of the whole economy by specifying which economic sectors play a role of hub in the economy. This means identifying which sectors have a strategic position in the market in order to assess their ability to affect others, taking into account the sector characteristics, in spreading external solicitations through the system.

We defined, in this analysis, municipalities as geographical samples and the number of employees for each industry as a feature.

Our assumption, in order to build the network, is that the morphology of the resources allocation (employees) in each sector is a proxy of the local production system. This micro-founded point of view allows us to associate with each city a pattern whose morphology is described in terms of allocation of resources employed in each sector. Especially relevant is that the nature of these spatial patterns is determined by the whole allocation structure of labor factor in the local economy [8]. This assumption allows us to define the relevance of each sector in the whole economy in terms of local industrial relevance.

From this hypothesis we can build the network. In our analysis the nodes of the network are the economic sectors and the links represent intersectorial closeness in the Euclidean space in terms of high productive similarity. In other words, spatial likelihood between sectors (the existence of a link between them) proves the existence of a relevant relationship in terms of spatial pattern distribution. This means that the role of a sector in the whole economy and the structural interdependence with other industries emerge from local patterns of industrial co-agglomeration.

Our network based approach takes into account a dataset obtained from matrix X, whose entries $x_{i,j}$ are i-samples of the local economies and j-features of the employees' numbers for each industry. We rescaled X into a new matrix Y whose entries $y_{i,j}$ are defined by a logistic function[2].

We rescaled matrix X by rows to preserve the key properties of the local distribution of employees across the different industries for each sample. In this manner each sample is represented as a pattern whose properties capture how the labor factor is locally allocated across industries [8].

Taking into account the objective of our work, i.e. to draw detailed network maps in order to help policymakers to define an efficient policy[3] [12], it seems necessary to determine in a unique way an indexed hierarchy [17] between industries.

This objective will be achieved by the *Minimum Spanning Tree (MST)*, a particular type of graph that connects all the vertices in a graph without forming any loop [7]

[2] A logistic function enables a non-linear scaling which tends to emphasize differences among the central values of the distribution, while being relatively unaffected by differentials that occur at its extremes.

[3] We remember that the policymaker has also the possibility to stress an economic structure with an incomplete information.

over the shortest path. In this way we are looking for a description of an indexed hierarchically structured system[4]. The spanning tree of the shortest length connecting the n sectors is associated with the distance matrix D, i.e. the Euclidean distance dij between pairs of normalized sectors y_i and y_j. The method of constructing an *MST* is well known in multivariate analysis [17].

Once the topological map of the network is defined, it is necessary to identify the centrality of each sector in order to select industries that play a crucial role because they are deeply connected sectors.

3 The Current Challenge of China

China currently faces big challenges following new national and international economic environments. Shocks are inevitable, but policymakers must find ways to extract the signals from the noise to understand what is over the horizon in order to better control the spreading of external stress in function of intersectoral interdependencies. As such, our methodology allows us to extract, from the Chinese economic structure, some information regarding the relevance level of sectors in terms of connectivity. To do that, it is important first of all to get a picture of China's growth trajectory.

The economic growth of China is largely labor intensive with high levels of fixed capital investment [3, 10]. It is deeply based on the mobilization of capital, labor and productivity. Since the beginning of the reforms, a large part of the growth was due to capital accumulation. The World Bank estimated that 2/3 of the economic growth of China, from 1985 to 1995, came from gross capital formation. Other studies stipulate the same conclusion [11]. This means that growth has largely been extensive growth: production capacity more than improved the productivity of existing units[5]. Productivity improvements have contributed one third to growth. The World Bank estimates that by moving a significant number of workers from agriculture to industry and services, growth will rise by 1.5 percent per year just because the productivity of a worker in service is greater than that of a farmer. Since 2002, the Chinese economy has entered a new phase with strong growth based on investments[6] and exports[7] as pillars of growth. Concerning investment, its dynamic over the last 10 years has targeted the improvement of the competitiveness of China's companies and the rebalancing between public and private firms. With 60 percent of the total investments, building investment looks as if it has been a strong driver and has generated an investment boom in downstream sectors like mining and processing of metals (aluminum,

[4] It is possible to show that a one to one relationship exists between an indexed hierarchy and an ultrameric set [19].

[5] While an increase of productivity, driven by technological change, is the pillar of long-term sustained economic growth.

[6] As a result of large expansionist policies of the Chinese authorities.

[7] In the absence of inflation pressures.

copper, iron and steel) [14]. Concerning exports, China with its competitive price (low labor costs) and its aggressive internal program of industrialization, has become a key player in the international market. China tooks following this dynamic an advantage of its price competitiveness linked to low labor costs, population dynamics and the quality of its workforce as well as its exchange rate policy to contain the appreciation of the local currency. This virtuous circle between exports and growth has made China mainly dependent on the international environment. Indeed, the recession that followed the insolvency of Lehman Brothers in 2008 affected China. Growth was reduced to 9 percent in 2009 following a decline of the external demand especially from the USA and a low inclination towards protectionism. Palley (2002) formulated a more general criticism of the export-led growth Model. He argues that this model has harmed developing countries in several ways (creating excess capacity, deflation, competition among countries and competition among workers from developing countries and industrialized countries). Under this competitive pressure, China today has lost its price competitiveness in favor of other countries such as Bangladesh, Malaysia, Vietnam and the Philippines. All these considerations suggest China should undertake some reforms which will likely stress the economic structure. Taking into account this current interrogation, our methodology allows us to outline properties of the Chinese economic structure in terms of network. This information is very helpful for policymakers since it allows to better control the spreading of an external stress in function of intersectoral interdependence.

4 Empirical Analysis

In this section we will show the most representative result of our approach by examining the employed Chinese population organized into 14 sectors and spread over 287 cities. The dataset gathers the overall number of the Chinese municipalities, therefore covering the entire country with reference to the year 2010[8]. We chose to analyze this year because of the availability of complete data.

As a result, the matrix $X_{i,j}$ has i= 1, . . ., N= 287 municipalities and j = 1, . . ., n=14 industries. Following our approach, the original dataset (number of local employees in each sector) is normalized by row (sample) in order to represent each sample as a pattern whose properties capture how the labor factor is locally allocated across the industries [8]. Then an Euclidean distance is calculated to capture how similar the pattern allocation of local resources is across industries[9]. The procedure concludes with the definition of the MST associated with the considered metric distance in order to define the indexed hierarchy between the n industries (nodes).

[8] Data is available at the China Data Center (http://chinadatacenter.org).

[9] Mantegna (1999) identifies, in his methodology, a metric which is defined using as a distance a function of the correlation coefficient computed between all pairs of nodes of the network.

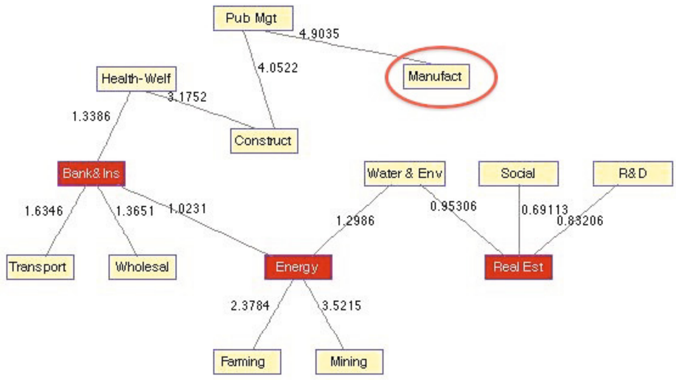

Fig. 1 Interconnection between Chinese economic sectors.

The main result of this network based approach is to map the Chinese economic system in a topological space built on similarities of patterns in terms of industrial employment, as shown in the following figure.

The diagram shows that the whole Chinese Economy may comply with a scale free structure (figure 1). What we are highlighting, by analyzing the MST, is the critical role of three sectors (Real estate, Financial services and Energy) in terms of their centrality [13] in order to explain the pattern of diffusion of biased economic policy effects or other exogenous stimulus. In some senses they are focal points for spreading external solicitation effects, at least with respect to the others with whom they are close, just because they occupy a central position in the mainstream of information flow in the network.

5 Conclusion

This network based approach seems very interesting because it helps policymakers, through the information regarding a path, to better control the effects of any external solicitations. This information is defined by the number of links. The links represent a major for the possible propagations of an external shock or a policy over a defined number of sectors: a sector with a few links can propagate less respect to other one with more dependences.

We analyzed the case of China in terms of local employment because the reforms expected by Chinese policymakers are likely to cause significant stress on the economy. Applying our approach to the Chinese economic structure, we have demonstrated that the Real Estate, Energy and Financial sectors have an important position because they are highly connected. Relationships across sectors could be the key to interpreting intersectoral dynamics in terms of local employment as a result of external solicitation including eventual actions of policymakers.

While pursuing the research illustrated in this paper, we learned that analyzing the Chinese economic structure as networks is an interesting research direction, which opens up a variety of new questions and requires the definition of a new analytical tool for the future.

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Regional Income Differentials in Italy: A MARS Analysis

Iacopo Odoardi and Fabrizio Muratore

Abstract We analyse the influence of 45 regressors that explain the existence of income differentials and other socio-economic spreads in the Italian regions. We use a multivariate adaptive regression splines analysis as a data-driven approach to detect relationships among variables in big data sets. The focus on regional areas allows us to consider economic contexts historically extremely distant in terms of growth and development. The considered time series include the pre-crisis economic period, the negative effects of the crisis and the originated recession. The independent variables chosen are based on the endogenous growth theory according to the knowledge economy, thus focusing on human capital and other intangible assets. Macroeconomic data and entrepreneurial competitiveness are also considered as control variables. The results are consistent with the findings of the recent economic literature.

Keywords Income differentials · Multivariate adaptive regression splines model · Artificial intelligence · Human capital

1 Introduction

The aim of this paper is to exploit the multidimensional information of a large number of regressors in explaining the evolution of a target macroeconomic variable, explaining the substantial differences in regional areas. Such differences are also so-called "North-South problems" that represent an obstacle to the socio-economic development of a country.

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The original idea of this work is to analyze simultaneously several social and economic aspects characterizing the 20 Italian regions. To do this, we select these regions because in this country there is an historical structural gap between the northern-central regions and the South. The difference is so relevant that by placing the Italian *per capita* income as 100, the northern regions mark a score of about 120 and the southern of 70-80 in the last decade (based on Istat data). This allows to study and compare two diverse socio-economic areas and find out what makes it difficult to bridge the several gaps. For this reason, we use a multivariate adaptive regression splines (hereafter MARS) analysis, that allows us to implement a tool of data mining in the perspective of Artificial Intelligence (AI). In synthesis, data mining is the process of finding correlations or patterns among dozens of fields in large relational databases that, for their structure and complexity, allows to detect relationships not always observable with traditional econometric techniques. Indeed, in this work the MARS analysis allows us to study a big data set, that is to consider simultaneously a target dependent variable and a significant number of regressors. We study a total of 46 variables related to the Italian regions, considering the years 2004-2013. This period includes the international economic pre-crisis of 2007-2008, the years with the worst financial and real effects due to the crisis, and the so-called “Great Recession”, that is the prolonged economic slowdown that has characterized this country. The analysis is mainly based on human capital data, that is a major income determinant in Western countries. In fact, education and training represent key variables in the light of the extensive literature on the knowledge economy. It is necessary, however, also to include control variables, and this implies to have more chance to find out the effective influences on the target variable. The latter is represented by the Gross Domestic Product (GDP) *per capita*, which explains adequately the regional differences and moreover is the main purpose of national and local public policies and of socio-economic investigation. Other variables, that are listed and detailed in Section 3, reflect the local economic structure, from the labor productivity to the business characteristics (competitiveness, innovation, ICTs, R&D). Several variables regard small businesses, typical of the Italian economy. Furthermore, we consider the relevance of the social capital (related to SMEs, such as in industrial districts) and well-known macroeconomic data on labor (necessary for explaining the support to the domestic aggregate demand).

2 The Relevant Socio-Economic Variables in the Knowledge Economy Era

Many determinants influence the formation and development of the national income, involving the multidimensional aspects of several related variables. The *endogenous growth theory* indicates the drivers of economic growth as components inside each system [16], [23]. In addition, in the *knowledge economy era*, the human capital [24], [5], [17] and other intangibles assets (R&D, continuous innovation, use of ICTs [3]) represent the competitive and sustainable resources in the long run for the advanced economies [15], [2]. Moreover, it is necessary that the various inputs are efficiently combined to create virtuous circles on the production side [9], [19], and thus socio-economic analysis must consider all the aspects. At the basis of the national human capital formation there are the schooling system [4], [18], [12], [21] and the lifelong learning programs [14], [1], [6]. The purpose of the investment in education is to increase labor productivity, also thanks to processes of *learning by doing* and *by using*. Of course, also the social aspect plays a fundamental role, as considered in this work, starting from the household level [8]. Finally, the human capital of individuals has a strong relation with our dependent variable, the average level of income [10].

In addition, the competiveness of several industries also depends on the human capital level, that makes it possible to remain efficient in international markets. This is highlighted by data on exports and this condition influences the entrepreneurial activity. In Italy, the widespread presence of industrial districts requires the specific study of small and medium businesses (with less than 50 and 250 employees). In fact, we use several variables on businesses to represent the different levels of regional strength and economic dynamism, and to observe the diverse level of opening to international markets [22].

3 The Selection of the Regressors: Explaining the GDP

All variables (2004-2013, Istat data, retrieved in January 2016) are selected to be directly comparable and to represent the main fields of socio-economic interest, as recorded in the previous Section 2, starting from the economic literature. The 45 independent variables (regressors in the MARS analysis in Section 4) follow sorted into homogeneous groups and explained:
Human capital

1. Share of the population aged 15-19 with at least the middle school diploma
2. Share of population aged 20-24 with at least upper secondary school diploma
3. Share of the population aged 25-64 with at most a lower second. level of ed.
4. Rate of tertiary educ. in the age group 30-34 years (population who has achieved a level of education of 5 and 6 (Isced97) in % of the population)
5. Adults employed in the age group 25-64 years who participate in training and education for 100 employed adults in the same age group (%)
6. Adult unemployed (unemployed and non-labor force) in the age group 25-64 years who participate in training and education for 100 unemployed adults
7. Adults (25-64) participating in lifelong learning (study or professional training) as a % of the population of the same age group

8. Index of attractiveness of universities (ratio between the net migration of students and the total number of students enrolled - %)
9. Young people education and professional training drop-out (share of population 18-24 years with at most a middle school diploma, which has not concluded a training course approved by the region lasting longer than two years and that does not attend school or participate in training activities)
10. Young NEET rate (young people between 15 and 29 years not occupied or in a regular education/training path as a % of the popul. - annual average)

Social capital

11. Capacity of development of social services (people aged 14 and over who carried out voluntary work on the total population aged 14 and over)
12. Index of regional poverty (households that live below the poverty line - %)
13. People at risk of poverty or social exclusion on the total of the resident population (% of the total population)

Businesses, competitiveness, innovation

14. Ability to export (value of exports of goods to GDP - %)
15. Openness of markets - imports (value of imports of goods to GDP - %)
16. Degree of economic dependence (net imports as a % of GDP)
17. Ability to export in sectors with a world dynamic demand (% on tot. exports)
18. Capacity of development of business services (work units in the "business services" of total annual work units (AWU) of market services - %)
19. Gross enrolment ratio in the commercial register (new businesses registered on the total number of businesses registered in the previous year - %)
20. Birth rate of businesses (ratio of businesses births in year *t* and businesses active in the same year - %)
21. Birth rate of businesses in the high knowledge intensity sectors (%s)
22. Net enrolment rates in the commercial register (new businesses registered minus closed down on the total of businesses registered in the previous year - %)
23. Net rate of turnover of businesses (difference between the birth and mortality rates of businesses - %)
24. Youth entrepreneurship (both sexes, %)
25. Female entrepreneurship (%)
26. Degree of spread of PC in businesses with more than 10 employees (%)
27. Diffusion index of websites of businesses (businesses with more than 10 employees of industry and services sectors that have a web site - %)
28. Index broadband penetration in businesses (businesses with more than 10 employees of industry and services sectors that have broadband connection - %)
29. Degree of Internet use in businesses (employees of businesses with more than 10 employees of ind. and serv. using computers connected to Internet - %)

Labor productivity

30. Labor productivity in industry excluding construction (value added for work unit in the same sector - thousands of Euros, constant 2010)
31. Labor productivity in the manufacturing industry (value added for work unit in the same sector - thousands of Euros, constant 2010)
32. Labor productivity in the trade (value added for work unit in the same sector - thousands of Euros, constant 2010)
33. Labor productivity in business services (value added for AWU in the same sectors - thousands of Euros, constant 2010)
34. Labor productivity in tourism (value added for AWU in the same sector - thousands of Euros, constant 2010)

Other macroeconomic variables

35. Intensity of capital accumulation (gross fixed capital formation - % of GDP)
36. Employment rate (persons employed aged 15-64 on the population - %)
37. Youth employment rate (employed people aged 15-29 in percent of the population in the corresponding age group - annual average)
38. Difference between male and female employment rate (absolute difference between male and female employment rates of aged 15-64 - %)
39. Unemployment rate (people seeking employment aged 15 years and older on the labor force of the corresponding age group - %)
40. Youth unemployment (people seeking employment aged 15 to 24 on the labor force of the same age group - %)
41. Incidence of long-term unemployment (share of persons seeking employment for more than 12 months on the tot. people seeking employment - %)
42. Risk on loans (default rate of cash loans - %)
43. Financing capacity (differential lending rates on loan to the Centre-North - %)
44. Percentage of total R&D expenditure on the GDP (% of GDP at current prices)
45. Degree of Internet use of households (Internet access on total households - %)

4 A Multivariate Adaptive Regression Splines Analysis on the Italian Regions

The multivariate adaptive regression splines model is an application of techniques for solving regression-type problems and in our study the aim is to estimate the values of a dependent variable from a set of predictors considering a non-parametric regression technique [7]. Our analysis is a multiple regression referred to a regression analysis that examines the effects of 45 predictors on the GDP *per capita* of each region (constant 2010). The purpose is to calculate a coefficient for each independent variable and thereafter consider only those with a statistical significance (see Table 1), showing the effect of each predictor on the target variable with other independent ones held constant [11]. The multivariate equation considering our case study is given as:

$$y = f(x) = \beta_0 + \sum_{i=1}^{n} x_i \beta_i + \varepsilon_i \quad (1)$$

This model uses two-sided truncated functions of the form $\pm(x-t)_+$ as basis functions for linear or nonlinear expansion, which approximates the relationships between the response and predictor variables. The basis functions and the model parameters (estimated via least square estimation) are combined to provide the predictions, assumed the inputs. The aim is to adjust the coefficient values to best fit the data. We obtain a geometrical procedure that is better than a standard approach, considering a recursive partitioning regression. The multivariate splines algorithm shapes models from two sided truncated functions of the predictors (x) of the form:

$$(x-t)_+ = \begin{Bmatrix} x-t & x>t \\ 0 & otherwise \end{Bmatrix} \quad (2)$$

Hence, the MARS model, considering a dependent variable y and M terms, can be specified in the subsequent equation [13]:

$$H_{ki}\left(x_{v(k,i)}\right) = \prod_{k=1}^{K} h_{ki} \quad (3)$$

where $x_{v(k,i)}$ is the predictor in the k^{th} of the i^{th} product. In Table 3 are shown only the predictors that are statistically significant regressors of the GDP *per capita*. We do not need to demonstrate better interpretative capacity of the MARS model compared to traditional multivariate techniques [20], which could not test simultaneously information in panel data as the one described here. The predictors explain the GDP *per capita* with an RSQ of 0,90. The most statistically significant results are reported in the following summary table. For each row in which there is a number in the last column, the influence sign on the dependent variable is observed in the GDP column, and the relevance is found in the first column, indicating the knots. The early knots (first column) indicate a greater relevance of the predictor of the row.

Table 1 MARS analysis on the Italian regions: coefficients, knots and basis functions

	GDP	*Variable and knot*	
Intercept	*30297,42*		
Term.1	*911,0717*	*Employment rate*	*63,64339*
Term.2	*-236,386*		
Term.3	*-80,505*	*Degree of econ. dependence*	*-4,111*
Term.4	*573,7319*		
Term.5	*110,3226*	*Labor product. bus. services*	*123,7365*
Term.6	*-23,4826*		
Term.7	*48,83536*	*Labor product. industry ex. co.*	*81,66909*
Term.8	*-120,412*		
Term.9	*-117,842*	*Risk on loans*	*2,35894*
Term.10	*682,9257*		
Term.11	*165,4292*	*Labor productivity tourism*	*34,70958*
Term.12	*-239,63*	*Female entrepreneurship*	*27,82934*
Term.13	*-317,353*		
Term.14	*-47,6739*	*People risk pov. or soc. excl.*	*19,56261*
Term.15	*211,6461*		
Term.16	*593,8075*	*Gross enroll. rat. com. reg.*	*6,595556*
Term.17	*-12,2053*	*Index of attract. universities*	*-72,4724*
Term.18	*-14,823*		

Note: max(0, independent-knot), otherwise max(0, knot-independent).

Source: our own elaborations on Istat data (retrieved on January 2016).

The MARS analysis provides a rank of relevance of the regressors. The employment rate is ranked primary (1st knot) with a positive sign, to show how the dynamism of the labor market is crucial to economic growth. The net import follows (3rd knot) with a negative sign, because the opening to foreign markets, and therefore the presence of strong exports, is essential for economic recovery, especially during periods of recession. As expected, the productivity of services and industry follow, highlighting that the value of the service sector strongly impacts on developed economies and, at the same time, the industrial sector remains a strong foundation for all markets. Of course we find the risk of loans with negative sign, underlining possible causes of businesses failure (we remember the credit crunch phenomena) and also showing the inefficiency of local financial systems in the selection and control of borrowers. Furthermore, we note the relevance of the productivity level in the tourism sector (11th knot) as income determinant in Italy, while the female entrepreneurship (12th knot) has negative influence. The risk of social exclusion influences the social capital and has a negative sign (at the 14th knot). The percentage value of new companies registered on the total ones in the previous year (16th knot) is an index of businesses' dynamism and at the same time represents the possibility of receiving funding and having the sustain of domestic aggregate demand. Finally, the ratio between the net migration of students and the total number of students enrolled in universities (negative, 17th knot) is relevant because the leakage of students can result in a reduction in aggregate demand caused by lower consumption in the region. On the light of the results, the

Centre-North – South differences are evident and well explained by the selected regressors, as in Fig.1 (dark grey for higher income). The presence of economic resources and the strengths of businesses in all sectors are considerably higher in the northern regions.

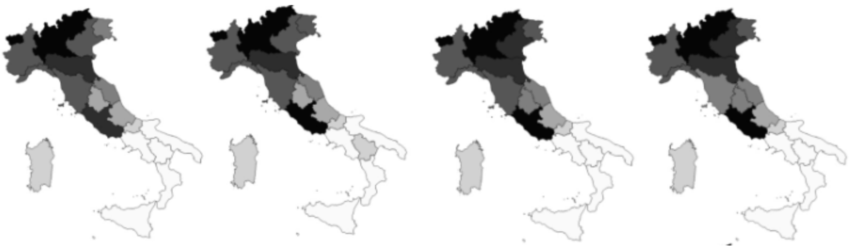

Fig. 1 Observed and estimated GDP *per capita* in 2004 (first two on the left) and 2013 (right), dark grey indicates higher values

5 Conclusions

The aim of this work is to explain the income differentials between the Centre-North and the South of Italy. We want to discover the reasons of the regional socio-economic gap (see Fig. 1) observed in the average income. This is made by analyzing the effective determinants of the GDP *per capita* (in Tab. 1). The application of the MARS model gave the expected results considering the economic theory with high statistical significance (RSQ of 0,90). From the selected 45 regressors on human capital, business activity and the general socio-economic context, 10 have better explained the so-called "North-South problem". For the statistically significant variables we observe the strong regional differences which are synthesized in the dependent variable. Openness to foreign market, employment level and productivity play a fundamental role. This is due to large disparities in investment levels, available resources and businesses work. In the North there is entrepreneurial vitality, efficient financial systems, willingness to improve the quality of human and physical capital. The outcomes are evident in the observed and estimated values of the GDP *per capita*. In the South, the economic downturn has damaged and distanced almost all the regions from the objective of the economic growth, and structural inefficiencies prevent to mend the (growing) gaps with the North.

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Data Aware Business Process Models: A Framework for the Analysis and Verification of Properties

Raffaele Dell'Aversana

Abstract Well before the computer age, Herbert A. Simon was a pioneer in extending systems thinking to business organizations, identifying and analyzing systemic business processes, and introducing flow diagrams as a representation of processes. Today Business Process Management is a discipline that provides a systematic approach to the development of more efficient and effective organizations, enabling quick adaptation to the changes of the business environment. For this reason modeling languages such as BPMN (Business Process Modeling and Notation, [1]) have a wide adoption in modern organizations. Such modeling languages are used for the design and reengineering of business processes and have the advantage of having a representation that is not only easy to understand by all the stakeholders but also machine processable, with tasks assigned to software or human agents based on the workflow and rules defined using BPMN.

It is desirable to have tools that give to the designer of the process the possibility of discovering potential problems in processes, ranging from the correctness of the model to the verification of properties of the model, such as conformance to business rules.

This paper presents a logic framework that enables the possibility of studying the properties of data-aware business processes, and gives directions for open research challenges.

Keywords BPMN · Logic Programming · Data-aware verification · Business process analysis · Business process re-engineering · Software agents · Human agents

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1 Introduction

Long time before the computer age, the Nobel laureate Herbert A. Simon was among the pioneers that identified the need of reasoning about organizations using the ideas of systems thinking. In *Organizations* [2] (by Herbert Simon and James March) there is a deep analysis of how organizations function, oriented to processes. The authors identify the interactions of individuals and the coordination of their behaviour as foundations for understanding organizations and introduce flow diagrams as a natural and easy way to represent processes.

Business processes, as defined today, can be considered goal-oriented design artifacts, like the one described by Herbert Simon in [3]: those artifacts need to conform to requirements of their inner and outer environments. The inner environment is composed by the actors, resources, business rules and flow structure of the process, while the outer environment is the one the process operates in, and includes external events (e.g. demands of its stakeholders), external resources and the technical and economic contexts. Simon defines the design of the artifact (business process) as the design of the interface between the two environments, and highlights the need of flexibility of the artifact, that is the ability to continue to meet its business goals by means of adapting to the variations of the environments or to changing requirements. Simon goes further describing two different ways of adaptation: reactive, where a change in the artifact happens as a reaction to a change, or proactive, where the artifact mutate in anticipation of a change.

The ideas of Simon have deeply influenced the birth of the Business Process Management discipline and the related software tools, used to analyze, design and implement business processes in organizations. The framework presented in this paper defines the foundations for a tool useful and usable to study the properties of the business processes in their environments and the ability of the business processes to meet the business goals.

2 Business Process Management

Nowadays there is a wide adoption of Business Process Management (BPM) solutions into industrial and business realities, because it gives to organizations the opportunity to improve governance, helping executives to measure and manage company resources, reduce costs, enhance efficiency and productivity. Usually the adoption of BPM starts from the analysis of existing business processes (BPs) and workflow within an organization and then on changing them (re-engineering) with the main purposes of improving productivity and reducing inefficiencies. Usually the processes are modeled using a BPMN compliant tool, and then transformed directly into an executable process, with tasks assigned to people (based on their roles) or executed by a software agent.

The verification of properties and correctness of the BPs is a challenging activity that require specific tools and methodologies; moreover, when reengineering a BP, it would be desirable to be able to guarantee that the modified BP preserves the properties of the original process and continue to meet its goals, as described by Simon for its goal-oriented design artifacts.

The standard approaches to business process analysis (e.g. [4, 5]) are process oriented and focused on the analysis of processes represented as a workflow graph with directed arcs that define all operations (*tasks*), their interactions and their planned order of execution, mostly abstracting away the underlying *data layer*. Consequently, the verification approach is oriented on checking properties of the control flow, like correct termination or *soundness*[6].

However in the real world BP are composed of workflow and data models, and consequently there is the need to be able to verify properties of the processes taking into account the data part. This is a quite challenging task, because the introduction of data model means that we have to analyze infinite-state systems.

In order to provide an integrated approach to BP verification, including both workflow and data modeling, several new methodologies have been proposed (for a survey, see [7]). All these methodologies define an abstraction of the data layer and identify techniques to perform verification and reasoning on the BPs including the data models. Some of the most relevant methodologies are the *artifact-centric* BP models [8, 9, 10, 11], the database oriented approach [12, 13], the Logic Programming methodologies [14, 15, 16]. All these approaches give possibilities to study properties of the BPs including the data layer, sometimes with some limitations on expressive power.

In this paper I propose a practical framework that gives the possibility to analyze BPs starting from the BPMN specification of a process, enriched with constraints and desired properties of the data. The BP can be translated into a logic program that can be analyzed using a Prolog tool based on Event Calculus [17, 18, 19] with Constraint Logic Programming over Finite Domains [20, 21]. The framework gives to the designers of BPs the possibility of working with their BPMN tools and analyze the properties using a simple approach based on Prolog queries.

3 Modeling Business Processes with Data

There are many tools (commercial or free) that can be used to model BPs using the BPMN notation. All these tools produce a standard output in XML format, compliant with the BPMN 2.0 specification[1, 22]. To give executability to a model the designer must add a lot of technical details, to specify the way it interacts with the data. For the purpose of verification of properties with data, a simple way to specify data and properties must be defined. In my model the data and their properties can be expressed using two standard BPMN components: the *Text Annotation Artifact* can be used to add special definitions and commands to each task, event or gateway that modify data or require to express a property on data, while the name property of the flow arcs can be used for the guards (conditions on data).

The business process shown in Fig. 1 has the purpose of showing a very simple example using annotations to express the data model. The process has a loop that updates values of some variables based on conditions on data. The annotation of the start event *s* declares two variables, *x* and *t* and implicitly presents a third variable, *n*, with undefined value (so, can have any possible integer value). The gateway *x2* is a choice point with an annotation containing the predicate *assume* that gives a hint about *n*: the verification tool can assume that, starting fron this point in the workflow, the variable has a positive value. The task named "Work" does an update over variables *x* and *n*, and the gateway *x1* goes back to *x2* or forward to the end event *E* according to the value of *n*, as specified in the guards. In the end event *E* the annotations gives conditions to check about two variables, to assert the correctness of the execution regarding the BP with data.

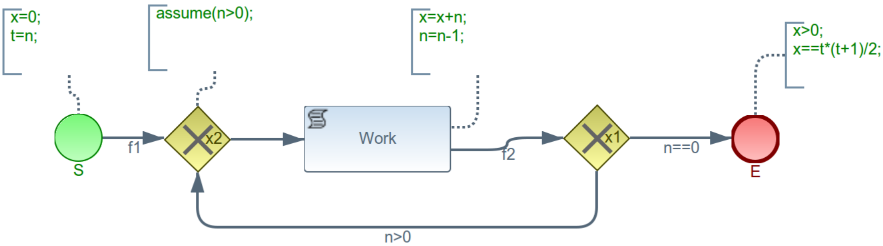

Fig. 1 A simple BP with data model

The syntax used to specify the data values and the conditions is Java-like and very easy to extend. The BPMN file (produced with any designer tool) can be transformed into Prolog facts using a parser developed for the presented framework. The parser software, written using Java and Scala language[23, 24], has a simple GUI and is quite easy to extend. It produces an output file that can be used for the verification steps, using the Logic model described hereafter, or produces an error if the artifacts cannot be parsed correctly.

4 Logic Model and Prolog Implementation

Processes described in BPMN are composed of four main items:

– *task*, represented with a rectangle, indicates activities executed inside a business process
– *event*, represented with a circle, indicates something that happen and can have an impact on the process

– *gateway*, represented with a diamond, indicates flow control points, where the activities can advance according to determined conditions and rules; gateways can act as a classical *if-then-else* construct but can also split the execution on more workflow in parallel
– *sequence flow*, represented with an arrow, used to connect flow elements with each other

The logic model here presented is similar to Event Calculus with reified *fluents*; the main elements of the model are:

– *fluents*: objects that can be used to describe the state of the *world* (includes both BPMN items and data objects)
– *S*: the state, that is a sequence of fluents that describe the state of the world at a certain point in time
– *actions*: things that can be executed in the world, indicates the domain of possible activities; there is a predicate that indicates when an action is executable, based on the state *S*; usually the actions are associated with the tasks
– *P*: the path, indicates the story of the states as they changed during the (simulated) execution
– *valid*: a validity function, indicates if a fluent is valid in a certain state

In the model the BP is represented with a set of reified fluents. The fundamental predicate that controls the advance of the execution state is called $next(S, F, W)$. S indicates the actual state, F is a fluent and W is (possibly) one of the valid states following the execution of the fluent F in the state *S*. If the predicate fails it means that it is not possible to advance from the state S using the fluent F. Here follows an example of the *next* predicate to advance a task, using a functional notation:

$$\begin{aligned} next(S, T, W) \leftarrow\ & T \in S \wedge task(T) \wedge Bs = outgoing(T) \\ & \wedge D = data(S) \\ & \wedge D1 = update(T, D) \\ & \wedge W = S - T - D + Bs + D1 \end{aligned}$$

In other words, to advance from *S* to *W* executing the task T:

– T must be valid in *S* and must be a task
– Bs is the set of the fluents that will be activated after the execution of the task *T*
– D is the data model included in S (set of fluents representing data)
– $D1$ is the data model after the execution of T (that is, after the application of the operations and rules described in the annotation artifact connected to T; if there is no artifact, then D1 will be exactly equal to D)
– W is equal to the state S minus the fluents T and D plus the new fluents Bs activated by the execution of T and the new data model $D1$

There are also other important predicates, based on the *next* predicate, that gives the possibility of veryfing properties of the BP model:

- $final$: indicates whether a state is final, that is if we reached the end of the execution (a state is final if it contains only the final event; if we reach the final event while the state contains other executable fluents, then the termination is considered not correct)
- $hasSuccessor$: indicates if it is possible to move from a particular state to a different one
- $findPath$: given a states, find a possible successor state and the path to reach it

Using the given predicates it is possible to verify some workflow properties. For example we can verify if a given business process P has a deadlock, that is a state T that is not final and has no successors; PT is the sequence of states (the path) that rise the deadlock, and gives useful informations to the designer to discover why the deadlock happens. Here is the predicate, in Prolog notation:

$$deadlock(P,T,PT) \leftarrow initialstate(P,S) \wedge findpath(S,T,PT) \\ \wedge \neg final(T) \wedge \neg hasSuccessor(T)$$

Another example is the predicate that checks if a process can reach the final state while there are still some executable fluents in the state:

$$final\_wrong(P,T,PT) \leftarrow initialstate(P,S) \wedge finalstate(P,E) \\ \wedge findpath(S,T,PT) \\ \wedge E \in T \wedge (\exists O \in T : E \neq O)$$

The predicate $final\_wrong$ has a process P as input and gives as output a state T and the path PT where happens the faulty condition (as usual, if it fails it means that the process always will terminate with a correct final state). The formula is easy to read: we find the initial state S, the final state E and a path from S to a state T that contains the final state E and also another fluent O that is different from E.

The third example is a query that checks if exists a reachable state where the conditions on data are not valid (and so the model does not comply to the specification given by the designer):

$$invalid\_data(P,T,PT) \leftarrow initialstate(P,S) \wedge findpath(S,T,PT) \\ \wedge \neg valid(T)$$

The predicate $valid$ checks if a given state has data whose values are compliant with the eventual rules in the annotation artifact.

The most common queries are embedded into the implementation to give the ability to check a variety of properties (e.g. improper termination, existence of dead tasks that can never be executed, existence of execution paths that violates conditions on data, ecc.). The model is easily configurable and extendable, so it is possible to add new kind of conditions and tests to be used into the artifacts, and add the implementations of the conditions and tests into the logic verifier. The software for the analysis and verification has been implemented using SWI-Prolog with the CLP(FD) module[21].

5 Conclusion and Future Work

The presented framework has been developed with two main objectives in mind: usability in real world scenarios and ability to be easily extended. The usability means that a BPMN analyst and designer must be able to use the tool easily and to find it useful and practical for the verification of properties of a business process; for example, after a re-engineering of a process the designer should be able to assess that the new process still has the properties of the original one. The current framework is easily usable for the parsing and conversion of the BPMN into the Prolog format (usable for the verifier) thanks to the GUI.

Regarding the ability to be extended, both the parser and the model have been designed to be easy to work with. The parser has been designed with extensibility as a requirement; it has been written in a mixed Object Oriented and Functional programming style using the Scala language and a small DSL (domain specific language) defined in it to ease the reading, parsing and transformation of the BPMN2 XML format. The model, written in Prolog, is composed of few basic predicates that can be composed together to give high expressive power, and make use of CLP over finite domains for the evaluations of the conditions on data.

In future the GUI will be extended to include also the possibility of running queries to check properties of the model, avoiding to go into the SWI-Prolog environment and being more user-friendly as a whole. Future research challenges regard the extension of the model: there is already work in progress to add more functionalities and extend it to add symbolic verification to add more power to the framework and a bigger set of predefined queries for the analysis of BP properties.

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