HUMBACE: Human and Social Behaviour Models for Agent-Based Computational Economics

With the advent of the global financial crisis of the past years, the reputation and suitability of the most widely used macroeconomic models that financial regulators commonly use, such as econometric and dynamic stochastic equilibrium models, have been questioned. Econometric models are empirical statistical models that are fitted to past data. However, although these models successfully forecast economic phenomena as long as they behave in the usual way, their predictions fail when unexpected factors alter economy, such as the intertwined breakdowns in housing, banking and hedge funds. Similarly, dynamic stochastic general equilibrium models, or DGSE models, perform well enough in a business-as-usual economy. However, they assume a perfect world, and by their very nature they do badly in a crisis, because their "dynamic stochastic" element only accounts for minor fluctuations around a state of equilibrium, and there is no equilibrium during crashes [1].

Making things worse, these macroeconomic models are now incapable of finding an uncontroversial way to recover economies from this difficult situation. The traditional recipes, promoted by the international institutions (IMF, OECD), are austerity programs that will provoke a reduction in the quality of life of wide social strata of the population. However, the anti-growth policies are not the only alternative to cope with the crisis. The exceptional measures taken by Iceland have shown how to overcome the economic disaster without falling into austerity plans. Obviously, this position does not aim to defend the default neither to extend the experience of this small country to the whole Europe, but just to point out a fact that has only happened in Iceland. Namely, some politicians and bankers were "charged with failing to prevent the banking crisis". This fact does not mean anything per se, but in a social and economic situation in which many people have lost their jobs or their money, a public punishment of those individuals who violated public trust can help to rebuild confidence in the institutions. If we consider that an extended level trust in the society will promote people's emotional processes such as confidence in the public institutions and patriotism, this could be useful to help to get out of the crisis, and the lesson learned may be that people must be sure that anyone who has misbehaved will be punished. On the one hand, with this restitution of trust in the public institutions people will be more willing to accept new economic measures promoted by them. On the other hand, this will also promote emotional processes such as fear to be punished, which will prevent people from committing fraud, such as tax evasion or money laundering. However, from our point of view an important aspect is that this result is very difficult to predict with the standard assumptions that underlie most of the economic models of behaviour. Therefore, new approaches to explain this type of behaviour are needed.

Since 2009, a bunch of proposals advocate for the use of alternative methods, specifically agent-based modelling methods, to model economic phenomena and avoid a financial crisis in the future [1], [2], [3], [4]. Agent-based modelling (ABM) is a relatively new approach to modelling complex systems composed of interacting, autonomous agents [5]. In ABM, agents are autonomous entities that have behaviours and interact with other agents, which also have their own behaviours. As a result of these interactions, individual behaviours (or even objectives, preferences, etc.) may be affected, emerging a global (or aggregated) behaviour of the whole system. Therefore, ABM offers a way to model social systems that are composed of agents who interact, learn from their experiences, and change their behaviours to adapt to the dynamics of their environment. ABM approaches that deal with the computational study of economic processes modelled as dynamic systems of interacting agents are also known as Agent-based Computational Economics (ACE) models [6]. These ACE models relax the assumptions of classical economics, in the sense that they do not assume fully rational and homogeneous agents interacting in a system with a long-run equilibrium state. Research in ACE has recently gained an increasing interest. ACE appears as a research topic in the main diffusion forums of agent-based modelling and simulation and economics. Also, two special issues in ACE are to appear in the number 27 of the *International Journal of Knowledge Engineering Review*.

However, despite their success, many economists and financial regulators are reluctant to use ACE models as prediction tools. There are several reasons behind this distrust. Many economists still prefer conventional mathematical models [4], even though ACE models can be mathematically sound too [7]. Also, a common groundless criticism is that ACE models may contain many variable parameters, so that it is not clear if their good performance relies more on their success in capturing the dynamics of the system, or just on a suitable tuning of these parameters. However, traditional economic models also have many parameters to tune and hence, they are subject to the same criticism. Other interesting advantage of ACE models is that they provide us a laboratory for exploring how various micro-level assumptions interact to produce aggregated macro-level patterns [8].

However, real people often act on the basis of emotional processes, such as trust or fear, and social processes, such as peer pressure or emotional contagion, topics that are largely ignored in many ACE models and that behavioural economics [9], and cognitive neuroscience [10] are now addressing. In this project, we will adapt ideas from these sciences in the area of ACE. The few considerations that ACE models have about the features that characterise the human behaviour motivate our research. Concretely, we aim at developing computational models of human and social behaviour that simulate how people make decisions in specific target domains, considering *emotional processes*, *social processes* and *rational factors*. Our thesis is that agents should behave in a more human-like fashion to be able to model these scenarios accurately. Therefore, agents need to embody more human-like computational models.

Behavioural economics use social, cognitive and emotional factors in understanding the economic decisions of human beings and human societies [9]. The standard economic model of human behaviour includes unrealistic traits like full rationality and unbounded selfishness, features that are modified by behavioural economics. However, departures from rationality produce emotional processes, for example, trust, overconfidence, optimism, and extrapolation. Behavioural models typically integrate insights from psychology with classical economic theory to determine the bounds of rationality of economic agents and how their decisions are affected by their irrational, self-sabotaging, and even altruistic behaviour [11]. Therefore, behavioural economics has also stimulated research on the role of emotional processes in economic behaviour. However, economists have only recently studied the role of emotions in decision-making [12], [13].

The different cultural background of people is another important factor that should be considered when modelling economic processes in which humans take part. Current research in behavioural economics studies how cultural transmission plays an important role in human behaviour, like human attitudes towards family, in the job market and cooperation [14]. Thus, our view is that theories about individualism, collectivism, uncertainty avoidance, masculinity, etc. should also be considered when modelling economic processes that involve people with very different cultural background, which is usually the case due to globalization.

Cognitive neuroscience, which focuses on the study of how psychological and cognitive functions are produced by the brain, can also play a major role in devising computational models of human behaviour in economic processes. The influence of emotional processes on decision-making has been largely ignored. However, studies from cognitive neuroscience provided empirical evidence that the mechanisms of emotion and cognition are closely related to each other [15]. Thus, understanding cognition does require the study of emotions and research on the role of emotions has yielded a number of important insights. One is that people are effectively transformed by emotions; the same person in different emotional states is likely to behave as differently as two people in the same emotional state. In this line, in the last decades, affective computing has emerged as a multidisciplinary research field spanning computer science and cognitive science. Affective computing is devoted to study and develop systems and devices that can recognize, interpret, process, and simulate human emotions. Some of the works in affective computing have led to the development of computational models of emotion and agents that embody such models of emotion [16]. However, as far as we are concerned none of these models have been proposed for the domain of agent-based economic

models, and specifically for the problem of providing models of rational, emotional and social processes in ACE, which we would like to deal with in this project.

There is also another important factor when modelling emotions to be embodied by the agents that are within a society of agents, as it usually happens in agent-based economic models. This factor is emotional contagion, which is a social process that determines the tendency for one's emotions to reflect the emotions of others [17]. Considering emotional contagion, we could design agents that can more accurately mimic human responses to emotional situations in their interactions. Also, there are other social factors to be considered in economic processes where humans participate, such as the degree of intimacy in relationships and the development of them [18]. To the best of our knowledge, there are no studies in the ACE discipline that consider both emotional processes and social processes such as relationships, their strength (in the form of intimacy), and their development (by means of exchanging information).

Furthermore, rational factors must also be taken into account when developing computational models of human behaviour in economic processes. These rational factors have a great importance for the adequate agent-based modelling of societies that have a set of norms that are aimed at regulating themselves. These norms are usually violated due to the protection of private interests, due to functional or cooperative motivations (i.e., the system performance improves through violating or ignoring norms), and other reasons [19]. Therefore, the agents that model the behaviour of the members of these societies must be able to make decisions about which and when norms are obeyed and violated. This requirement entails the development of reasoning models that take into account rational processes that consider the impact of norms and their enforcement (sanctions and rewards) on the agent's goals. Besides that, there are also emotional factors that take into account the emotional processes triggered when the agent violates or complies with norms [12].

Finally, we also seek to consider evidences from experimental works on cognitive neuroscience, which are usually ignored in ACE. Recent advances in cognitive neuroscience are uncovering the neural bases of cognitive, emotional, and social processes [20]. To this aim, cognitive neuroscience relies on Functional Magnetic Resonance Imaging (fMRI) tools, which measure brain activity by detecting associated changes in blood flow. Using fMRI tools, cognitive neuroscientists are able to know which brain areas activate during cognition. Thus, we can learn about the functionality of the brain areas associated to the emotional, social and rational mental processes we seek to model. Some of the advances from cognitive neuroscience are starting to be considered in other disciplines such as economics. Neuroeconomics is a new field of study that integrates economy, psychology and neuroscience which main goal is to establish a solid neurobiological basis of economic behaviour. The use of fMRI tools and other methods of neuroscience, such as neuroelectric recordings, have allowed the study of correlations between the basic concepts of economics and psychology and neural activity, uncovering the importance of mental states in economic decision-making. Thus, we consider that cognitive neuroscience can be a powerful tool for inspiring new models of ACE that are more human-like.

We have previous experience in game theory [21] [22], behavioural economics [14], experimental economics [23] and cognitive neuroscience [24] [25]. We also have extensive experience in agent-based modelling and agent-based simulation. In this area, we have proposed models and validated them in the domain of social simulation [26]. Specifically, we have proposed a model and validated it for simulating the migration process that considers micro-level interactions of labour and financial markets to migration processes. Moreover, we have experience in agent-supported simulation environments for intelligent manufacturing applied to a metal-mechanic manufacturing enterprise [27]. The new computational models of human and social behaviour to be developed in this project will be incorporated into the models and architectures of agreement technologies [28] (automated negotiation, virtual organizations, norms, trust and reputation, argumentation, etc.) and multi-agent systems (MAS architecture and platforms, MAS development technologies, learning in MAS, etc.) that we have already developed in the research group "Grupo de Investigación en Tecnología Informática e Inteligencia Artificial" (http://gti-ia.upv.es) of the Universitat Politècnica de València (Spain).

The resulting infrastructures will support and facilitate the development of ACE applications.

These infrastructures will be used to implement an agent-based model of what we call “the Iceland case study”. Based on this case, we are interested in investigating whether the punishment of public trust violators is a way to restore trust emotional processes and, hence, how to design better institutions that promote trust and economic growth. Our aim is to model how emotional processes of trusting and social processes of reciprocating may develop among boundedly rational and emotional agents. The proposed model will be able to simulate the emotional, social and rational processes that led the Iceland society to accept and observe the economic measures promoted by the national public institutions, which allowed the country to recover quickly from the financial crisis without falling into anti-social or anti-growth policies. The main objective of the model goes beyond the simulation of a computational model of human behaviour that takes into account the factors that gave rise to the willingness of the Iceland society for observing new economic reforms. More importantly, in the long term, it is aimed at providing a laboratory for exploring how similar measures would be accepted by other European societies, especially those that are immersed in a severe economic crisis and are on the verge of needing a bailout from the European community. To this aim, we want to analyse the evolution of an aggregate behaviour of trust and trustworthiness in a society composed by heterogeneous agents that are interacting playing social dilemmas. The heterogeneity comes from endowing these agents with different emotional and reciprocal modules that allows them to mimic a human-like behaviour. Agents can individually use a punishment capacity triggered by the emotion experimented in a strategic economic game or collectively decide to build a public endogenous sanctioning institution to punish norm violators. In this context we want to analyse the distribution of different aggregate behaviour generated by the dynamic interaction of heterogeneous types of emotional agents that can give rise to some equilibria. Our objective is to characterize the basin of attraction of these equilibria and to check if this aggregate behaviour is compatible with the levels of the trust perception observed in real societies. We can have a polymorphic population, in which each agent can choose different behaviour or a monomorphic population. Finally, we also want to investigate the coevolution of a public punishment institution generated by a political voting mechanism of the agents and the distribution of the aggregated behaviour.

In this project, we will extensively validate and verify the new models that we will develop both from the agent-based and from the economic theory perspectives. To this aim, as these models are aimed at reproducing human behaviour as accurately as possible, we plan to conduct a series of experiments in which human beings will take part. Thus, we will be able to validate that the proposed models behave as humans would in the specific scenario of our proposal. Specifically, we will use the laboratory for research in Experimental Economics LINEEX [23], a research facility (one of the largest European laboratories on the subject) of the research group “ERICES”, the Center for Research in Social and Economic Behavior, at the University of Valencia. Since 1998 LINEEX is a venue for bringing together faculty and graduate students on the fields of behavioural and experimental economics, having developed several research projects during these years. Thus, in this project we will develop experiments to test human models of behaviour, using the methodology of experimental economics. Our goal is to identify when models are good descriptions of behaviour, and when behaviour deviates from the predictions of the theoretical models. Moreover, to complement the data obtained in these experiments, we will also conduct experiments using fMRI tools and other methods of neuroscience in The Social Cognitive Neuroscience Laboratory LabNSC [29] of the University of Valencia. As stated above, fMRI tools and neuroelectric recordings can create maps of the brain of the humans in the experiments with high accuracy. In terms of variable selection of all of the factors that we aim at considering, brain imaging tools can also help guide if a variable should exist in a model, i.e., if the expected brain activation associated with a certain variable is not observed, this variable might be excluded from the model.

The main objectives of our project are: (1) to analyse and characterize the behaviour of humans and human societies in the context of the proposed “Iceland case study”; (2) to produce

computational models of human and social behaviour that take into account emotional, social and rational processes; (3) to incorporate these computational models into our current Agreement and Agent technologies to produce simulation infrastructures of human and social behaviour; and (4) to validate these computational models by simulating human and social behaviour using the infrastructures developed for the Iceland study and comparing the results obtained to the observed human and social behaviour for the case study.

To achieve the proposed objectives we will work as a multidisciplinary team comprised by experts in agent-based simulation, agreement technologies, multi-agent systems, behavioural economics, experimental economics and cognitive neuroscience. We propose a work plan organized in the following work packages (WPs). WP1 will focus on the Iceland case study and it will guide all the subsequent research. Specifically, we will analyse and investigate the required human and social behaviours in WP1. Experts on behavioural and experimental economics (WP2) and experts on cognitive neuroscience (WP3) will conduct this work. The results of WP2 and WP3 will be models of human and social behaviour that will serve as the basis to develop computational models by experts in agent-based simulation, agreement technologies and multi-agent systems (WP4 and WP5). In turn, these computational models will be validated in WP1, by implementing our solutions to the case study, thus, entering a loop until satisfactory results are obtained.

The main expected impact of the project would be the ability to simulate and predict economic processes in human societies, taken into account emotional, social and rational factors. In this way, the simulation infrastructures developed in this project could be the base of decision-making tools that will improve the capacity of financial regulators in modelling and evaluating new economic policies in the European Union.

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