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Macroeconomies as constructively rational games

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ABSTRACT

Real-world decision-makers are forced to be locally constructive; that is, their decisions are necessarily constrained by their interaction networks, information, beliefs, and physical states. This study transforms an otherwise standard dynamic macroeconomic model into an open-ended dynamic game by requiring consumers and firms with intertemporal utility and profit objectives to be locally constructive. Tested locally constructive decision processes for the consumers and firms range from simple reactive reinforcement learning to adaptive dynamic programming (ADP). Computational experiments are used to explore macroeconomic performance under alternative decision-process combinations relative to a social planner benchmark solution. A key finding is that simpler decision processes can outperform more sophisticated decision processes such as ADP. However, memory length permitting some degree of adaptive foresight is critical for good performance.

1. Introduction

Decision-makers in real-world macroeconomies are necessarily limited to *locally constructive* actions, that is, to actions constrained by their interaction networks, information, beliefs, and physical states. In contrast, the actions of agents in current macroeconomic models are typically not locally constructive because they are constrained by externally imposed coordination and optimality restrictions. Key examples include the global market clearing conditions and strong-form rational expectations postulates imposed in standard *dynamic stochastic general equilibrium (DSGE)* models based on Smets and Wouters (2003).

These observations raise the following important challenge. Suppose all actions within an otherwise standard macroeconomic model are required to be locally constructive, unsupported by externally imposed coordination and optimality restrictions. What form could these locally constructive actions take to ensure good outcomes, not only for the individual participants but also for the macroeconomy as a whole?

This study addresses this challenge for a relatively simple macroeconomic model, referred to as the *Dynamic Macroeconomic (DM) Game*. Consumers and firms in the DM Game interact over time in labor and goods markets modeled as

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double auctions with uniform pricing rules. Each consumer desires to maximize his expected intertemporal (lifetime) utility subject to budget constraints, and each firm desires to maximize its expected intertemporal profit subject to technology constraints.

However, in a departure from standard macroeconomic modeling, consumers and firms in the DM Game are required to be *constructively rational* in the following sense. First, the specification by these agents of their objective functions, decision domains, and decision rules mapping decision domains into decision selections must be locally constructive actions. Second, the successive determination of DM-Game outcomes must be a purely historical process, unaided by externally imposed coordination and optimality restrictions.

To investigate the implications of constructive rationality for the DM Game, the decision domains for consumers and firms are expressed in stationary form, as vectors of possible parameter selections. In each successive time period an agent's selection of a decision (parameter vector) maps into a sequence of parameterized supply and demand functions for current and future markets, conditional on the agent's current information, beliefs, and physical state.

Computational experiments are then conducted in which consumers and firms make successive selections from their decision domains in accordance with decision processes ranging from simple adaptation to sophisticated anticipatory learning. These decision processes include: (i) a modified version of a reactive reinforcement learning method originally developed by Roth and Erev (1995) and Erev and Roth (1998) on the basis of findings from human-subject experiments; (ii) a forward-looking learning method developed by Watkins (1989), called Q-learning; (iii) a forward-looking rolling-horizon learning method (Alden and Smith, 1992); and (iv) an adaptive dynamic programming (ADP) learning method based on value-function approximation.

A key issue of interest is which decision-process combinations come closest to achieving the benchmark optimal solution obtainable by a fully informed social planner. In particular, do the decision processes involving relatively more sophisticated use of information tend to result in relatively higher welfare outcomes, either for the individual decision-makers or for the economy at large? Since previous experimental findings have shown that minimally informed traders using relatively unsophisticated decision processes can match or exceed the performance of better informed traders in some market contexts (Gode and Sunder, 1993; Smith, 2008), the answer to this question is not obvious *a priori*. A related issue of interest is which (if any) decision-process combinations constitute Nash equilibria and/or Pareto optimal solutions for the DM Game.

A key finding of this study is that good performance in the DM Game requires decision-makers to engage both in the exploitation of their current information and in searches for new information. Simpler decision processes can outperform more sophisticated decision processes, but only if the simpler processes entail memory lengths permitting some degree of adaptive foresight. Overall, the best performance is achieved when the consumers and firms use rolling-horizon learning methods.

This study is organized as follows. The relationship of our work to previous research is more carefully considered in Section 2, with a particular focus on learning in macroeconomic contexts. Section 3 sets out the basic structure of the DM Game together with its market and payment processes. Section 4 explains the decision processes implemented by the DM-Game consumers and firms, and Section 5 introduces and solves the social planner model used as a benchmark of comparison for our computational experiments. The sensitivity design for our computational experiments is described in Section 6, and key findings from these computational experiments are reported in Section 7. Section 8 concludes. Technical implementation aspects are relegated to the Appendix, and the code is available at https://github.com/wilfeli/DMGameBasic.

2. Relationship to previous research

Numerous previous researchers have emphasized the importance and complexity of modeling real-world decision processes. Examples include Simon (1978), Dosi and Egidi (1991), Stiglitz (2002), Smith (2008), Howitt (2008), Kahneman (2011), Kirman (2011), Hommes (2013), and Arthur (2015). Practitioners have also been interested in obtaining an improved understanding of these processes; see, e.g., a recent report issued by Trichet (2010), a former President of the European Central Bank.

Current macroeconomic models are surely complex. For example, standard DSGE models typically include consumers and firms that solve intertemporal utility and profit maximization problems subject to intertemporal constraints, conditional on announced government policy rules; see, for example, Sbordone et al. (2010) and Tovar (2009). Yet, to avoid aggregation and coordination issues, these models also typically assume the existence of representative consumer and firm agents with strong forms of rational expectations. This reliance on representative agents with rational expectations has been criticized on the grounds it prevents the study of learning and coordination issues critical for understanding the operation of real-world macroeconomies (Howitt, 2012).

Recently, however, a growing number of researchers have become interested in the study of dynamic macroeconomic systems for which agents are forward-looking optimizers with incomplete knowledge about the structure of the economy. As surveyed in Honkapohja et al. (2012) and Evans and Honkapohja (2013), the standard context assumed in this literature is that a representative consumer[1] with learning capabilities resides in a dynamic world consisting of itself, a representative

[1] Some researchers assume a compact continuum of consumers exhibiting some degree of heterogeneity in their preferences for consumption versus leisure; see, e.g., Milani (2005). However, efficient risk-sharing arrangements are then typically assumed so that the consumers in fact face identical intertemporal budget constraints and behave the same in equilibrium, effectively reducing the economy to a representative consumer economy.