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Modeling expectations in agent-based models — An application to central bank's communication and monetary policy

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ABSTRACT

Expectations play a major role in macroeconomic dynamics, especially regarding the conduct of monetary policy. Yet, modeling the interplay between communication, expectations and aggregate outcomes remains a challenging task, mainly because this requires deviation from the paradigm of rational expectations and perfect information. While agent-based macro models allow for such a deviation, their representation of expectations dynamics often remains simplistic. This paper introduces an expectation formation model which allows us to integrate a wide range of information disclosed by central banks. This expectation model is then integrated to the macroeconomic ABM developed in Salle et al. 2013 — [*Economic Modelling*, 2013, 34, 114–128], and yields aggregate results strongly in line with empirical evidence. In particular, we find that i) opacity is always sub-optimal, giving rise to the so-called opacity bias, ii) communication loosens the trade-off between the two objectives of monetary policy, and iii) forward guidance acts as a partial substitute for policy actions, and softens the optimal policy responses. This expectation model appears therefore promising to develop macroeconomic agent-based models.

1. Introduction

Rational expectations (hereafter, REs) are not a non-controversial assumption in the economic literature. REs imply that agents know the form of the underlying economic model, and are able to process all the relevant information, so that their expectations on average coincide with the true conditional law of motion of the economic variables. An extensive literature documents the lack of plausibility of such a strong assumption by advocating information and cognitive limitations of agents in their real decision-making.[1] Furthermore, RE cannot be transposed as such in agent-based models (hereafter ABMs), because these models are highly non-linear, and imply that agents are not able to see the whole picture of the economy in which they evolve and make decisions.[2] Consequently, the underlying macro-economic model is not available to the agents.

The lack of alternatives to RE within such frameworks has forced the state-of-the-art agent-based literature to stick to the use of simplistic assumptions concerning agents' expectations. For instance, Dosi et al. (2010, 2013) assume that firms form naive expectations about their future demand. Oeffner (2008) makes the same assumption concerning inflation expectations. Ashraf and Howitt (2012) assume that they are simply equal to the central bank's inflation target. While REs are probably too sophisticated to model real agents' expectations, such simple assumptions are obviously too limited to be realistic neither. Some other ABMs even abstract from modeling explicitly the way agents form expectations, and assume that they proceed by simple adjustments of their economic decision variables. This is the case, inter alia, in Seppecher (2012) and Lengnick (2013). However, expectations play a major role in economic dynamics. The dynamics of expectations play a central role in the New Keynesian models, which constitute with no doubt the current paradigm in macro-modeling (see Woodford (2003)). Furthermore, whether agents have RE, or whether they hold homogeneous or heterogeneous expectations turn out to dramatically influence macroeconomic dynamics, and the resulting policy recommendations.[3] Neglecting the expectation dynamics appears therefore as a major flaw of existing (macro)-economic ABMs. This is

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[1] See, notably, evidence collected in Simon (1996), and Hommes (2011) for a review in experiments with human subjects.

[2] See Tesfatsion and Judd (2006) or Delli Gatti et al. (2011) for an overview of ABMs.

[3] This has been analyzed mostly for monetary policy; see e.g. De Grauwe (2011), Branch and Evans (2011), Massaro (2013).

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all the more disappointing as these models are attracting a growing attention in macroeconomics, because they offer an alternative way to optimized models of providing micro-foundations to macroeconomic dynamics. They have been proved to be able to replicate at the same time micro and macro empirical regularities, and to generate endogenous business cycles, while abstracting from the very demanding assumptions of optimization and representative agents.

In this paper, we offer an expectation model which presents several interesting features, and we provide an application of this model within a macro ABM. Our expectation model is based on an artificial neural network (hereafter ANN, see Masters (1993) for a comprehensive exposition). It is easy to implement, as only the list of information available to the agents is required for them to form expectations, this information being private or public. Therefore, the model can accommodate homogeneous or heterogeneous expectations. It does not require the relation between information and the resulting variable to forecast to be linear, and can deal with non-linearities. Such an expectation model is also an evolving structure, which continuously adapts to the changes in the economic environment, and notably to policy changes. Consequently, expectations formed through this model allow for policy analyses that are robust to the Lucas critique. The behavioral interpretation of this model is also quite easy: agents form and update a "mental model" of their environment, which gives them the possibility of generalizing, i.e. forming beliefs in situations that they have never encountered before. It does not require agents to have the knowledge of the structure of the economy beforehand, nor this structure to remain stable, as REs do. It rather represents a very flexible and reactive form of adaptive learning.

We then plug the ANN-based expectation model in a macroeconomic ABM (hereafter MABM). In our application, agents form inflation expectations based on the observation of macroeconomic variables, and the information disclosed by the central bank (hereafter CB), including the values of its objectives and its internal forecasts of inflation, output gap and interest rate. The issue of CB communication and expectations is of particular interest because expectations have become the primary concern of CBs over the past twenty years, and a key channel of the transmission mechanism of monetary policy (Geraats (2009)). However, as underlined by Svensson (2009, p.11), the theoretical literature has to consider departures either from REs, or from perfect information to give a rationale to CB's communication: "*in a hypothetical world of a fully informed and rational private sector in a stationary environment with a stationary monetary policy, symmetric information between the CB and the rest of the economy, and rational expectations, there is no specific role for CB communication*". The intrinsic features of MABMs precisely allow for such departures, because they allow us to release both the RE hypothesis, by instead modeling procedural rationality *à la* Simon (1971), and the representative agent assumption, by considering heterogeneous and interacting agents. These two elements are highly likely to make the study of communication and expectations a particularly relevant, yet challenging task.[4]

This paper pursues such a task in the MABM introduced in Salle et al. (2013b). The main reason why we choose to elaborate on this model is that, to the best of our knowledge, this is the only MABM designed to investigate the interplay between expectations and macroeconomic stabilization through monetary policy. Specifically, this MABM includes an explicit expectational channel of monetary policy, in line with the modern view of central bankers as "managers of expectations" (Woodford (2005)), while keeping the structure of the model as close as possible to the baseline New Keynesian model. In Salle et al. (2013a, 2013b) we provide a detailed analysis of the functioning of the MABM, by putting an emphasis on the transmission channels of monetary policy, especially the expectation channel. We show that the model displays sounds and empirically relevant aggregate behavior, and can therefore be considered as "validated". This analysis sheds further light and credibility on the results from our numerical simulations.

With this framework at end, we consider different transparency policies of the CB, and check the consistency of our results in terms of macroeconomic performances with empirical evidence and previous theoretical results. We obtain three main observations which are fully in line with these well-established results. First, opacity is always sub-optimal, giving rise to the so-called opacity bias. Second, communication loosens the trade-off between the two objectives of monetary policy. Third, communication acts as a partial substitute for policy actions, and softens the optimal reactions of the Taylor rule, while improving the trade-off between inflation and output gap stabilization through a better control of inflation expectations. The relevance of these results indicates that the suggested expectational model constitutes a promising model of boundedly-rational expectations in agent-based frameworks.

The rest of the paper is organized as follows. The ANN-based expectational model is described in Section 2, the underlying MABM is presented in Section 3, Section 4 explains the simulation protocol and the way we analyze the simulation results, which are presented in Section 5. Section 6 concludes.

2. A model of inflation expectation using CB information

We introduce a model of "boundedly rational" expectations based on an ANN, that can be applied to a wide range of economic contexts, e.g. expectations of profits in a product market, rates of return in asset-pricing models, portfolio or consumption decisions in intertemporal problem solving. We first review the economic literature using ANNs as a learning mechanism, and then apply the expectation model to the formation of inflation expectations using CB information.

2.1. The use of ANN in economics: an overview

In economics, ANNs have been mostly used as predictors of time series, and only in few works as a way to model learning of boundedly rational agents.[5] For instance, Salmon (1995) implements an ANN in two models: a dynamic infinite-horizon game *à la* Barro & Gordon in which agents try to infer the CB's preferences (see Cukierman (1986)), and an hyperinflation model with two equilibria, namely a low- and a high-inflation equilibria (see Sargent and Wallace (1987) and Marcet and Sargent (1989)). Salmon shows that the ANN learning converges towards more favorable configurations than least-squares learning does, in both models.[6] Cho and Sargent (1997) use an ANN in the Kydland and Prescott (1977) repeated game, in which agents learn the CB's credibility. They show that commitment mechanisms are desirable, because ANN learning does not necessarily yield the CB to establish its reputation, and to deliver the low inflation equilibrium. But this learning mechanism limits the set of possible RE equilibria. In the same environment, Arifovic and Yıldızoğlu (2014) apply an adaptive learning mechanism based on an ANN to the policy maker (i.e. the CB), and show that the model consistently selects the Ramsey outcome. This ANN-based learning model is the only one in line with experimental evidence. Heinemann (2000) shows that stability conditions of the

[4] So far, a strand of the literature has considered imperfect information, see e.g. Walsh (2006, 2008) and Demertzis and Viegi (2009). Another strand has explored learning, mostly using econometric learning, see e.g. Orphanides and Williams (2005, 2007). For a comprehensive survey of this literature, see Eijffinger and van der Cruijsen (2007) or Geraats (2014*a*). Nevertheless, all this literature keeps the underlying macroeconomic model, based on optimizing homogeneous agents, unchanged.

[5] See Cho and Sargent (1996) for a review of this literature, especially in game theory; see also White (1992), Herbrich et al. (1999) or Evans and Honkapohja (2001, Chap. 15) in macroeconomics.

[6] More precisely, ANN learning results in a limitation of the inflation bias in the first model, and in convergence towards the low inflation rate in the second model.