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A method for agent-based models validation

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ABSTRACT

This paper proposes a new method to empirically validate simulation models that generate artificial time series data comparable with real-world data. The approach is based on comparing structures of vector autoregression models which are estimated from both artificial and real-world data by means of causal search algorithms. This relatively simple procedure is able to tackle both the problem of confronting theoretical simulation models with the data and the problem of comparing different models in terms of their empirical reliability. Moreover the paper provides an application of the validation procedure to the agent-based macroeconomic model proposed by Dosi et al. (2015).

> Although demonstrative simulation models are useful,
> not least at performing *"what if"* exercises of exploration of different models,
> policy analysis requires validated, descriptive simulation models.
> Marks (2013)

1. Introduction

Economics, as any scientific discipline intended to inform policy, has inevitably addressed questions related to identification and measurement of causes and effects. This paper, by identifying and comparing causal structures, proposes a method that improves the empirical reliability of policy-oriented simulation models.

The foundation of the *Econometric Society* in 1930 paved the way for a rigorous and formal approach to the analysis of causality, which, as Heckman (2000) points out, constituted the major contribution of econometrics.[1] In the post World War II period causal claims were introduced in macroeconomics by means of aggregate, mechanic and dynamic models in which the *ex-ante* use of economic theory was pivotal. Under this approach the causal process used to be partitioned in a deterministic component and a random component. The former was meant to reflect the causal relations dictated by

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[1] As Hoover (2004) has shown, however, causal language has not always been explicit in economics and in the sciences in general. In the first half of the twentieth century, under the influence of Karl Pearson, Ernst Mach and Bertrand Russell, many research scientists endeavoured to eschew causal concepts in order to privilege functional and statistical dependencies (Illari et al., 2011). Explicit discussions of causality revived in the second half of the last century (Hoover, 2004). See also Granger (1980).

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economic theory. The condition for it to be considered "valid" was to have the random component satisfying the standard Gauss–Markov statistical properties. Such a methodology goes under the name of *Cowles Commission* or *Simultaneous Equations Model* (SEM) approach. The most prominent proposers were Haavelmo (1944) and Koopmans (1950). This approach has been strongly criticized by Lucas (1976) and Sims (1980) on theoretical and methodological grounds respectively: the former insisted that individuals endowed with rational expectations would have anticipated the policy interventions supported by SEMs and their behaviour would have brought results opposite to the ones predicted by SEMs; the latter instead stressed the fact that in the *Cowles Commission* approach the distinction between endogenous and exogenous variables was *ad hoc*, in order to ensure system identifiability.

Taking as starting points the Lucas (1976) and Sims (1980) critiques, Kydland and Prescott (1982) paved the way for a new class of models, becoming the founding fathers of the stream of literature that goes under the name of *Real Business Cycle* (RBC) theory and which then evolved in what today is known as the *Dynamic Stochastic General Equilibrium* (DSGE) approach. These types of models are nowadays the most widely used to draw and to evaluate policy claims because they bear the advantage of simultaneously addressing two critical issues about causal structures. On the one hand, under the acceptance of the rational expectation hypothesis, the structure modelled by the RBC/DSGE approach remains invariant under policy intervention because it takes into account the forward-looking behaviour of the economic agents. On the other hand, the theoretical structure has an empirical counterpart in which the distinction between endogenous and exogenous variables is eschewed. However, some of the theoretical assumptions required by this class of models, in particular those related to the agents behaviour, are somehow too stringent, patently unreal (see Kirman, 1989, 1992).

As an alternative to the RBC/DSGE strategy, and to overcome some of the above mentioned assumptions, the *agent-based* (ABM) class of models has emerged. This approach proposes to model the macroeconomic structure as an emerging property stemming from the interaction between heterogeneous and bounded rational economic actors.[2] This modelling strategy has been applied to macroeconomic theory for only a decade, but it rapidly gained a significant success and in the recent years has begun to be perceived as a new valuable paradigm, able to provide a viable alternative to the DSGE framework. An ABM is in fact a useful and very flexible tool for performing rich policy experiments and for evaluating their implications. Among the main advantages of the ABM strategy is the possibility of analysing endogenously generated booms and busts and of studying the reaction of the economy to different stimuli, applied not only around a fictitious locally stable steady state of the economy but also in periods of distress.

But the most serious methodological problem ABM experience nowadays is their unclear relationship with the empirical evidence. This paper aims to address this issue. The difficulties of the ABM approach, which represent the counterpart of its flexibility, are perceived both in the model-data confrontation and in the comparison of different models investigating the same piece of evidence. The value of ABMs has been up to now evaluated according to their ex-post ability to reproduce a number of stylized facts even if other validation procedures are available (see Fagiolo et al., 2007). We argue that such an evaluation strategy is not rigorous enough. Indeed the reproduction, no matter how robust, of a set of statistical properties of the data by a model is a relatively weak form of validation, since, in general, given a set of statistical dependencies, there are possibly many causal structures that may have generated them. Thus models that incorporate different causal structures, on which diverse and even opposite practical policy suggestions can be grounded, may well replicate the same empirical facts.[3]

The paper is organized as follows. Section 2 reviews the literature on validation of simulated models. Section 3 describes some recent development concerning data-driven identification procedures for vector autoregressive processes; these are at the core of our validation algorithm, which is presented extensively in Section 4. Section 5 provides a first application of our validation method to the *"Schumpeter meeting Keynes"* model proposed by Dosi et al. (2015). Section 6 concludes. Four appendices follow with additional technical details.

2. On the comparison between models and data

DSGE models are compared to the data in two ways. The first and traditional approach is through calibration, in which the parameters of the model are chosen from pre-existing empirical microeconomic studies or are fixed according to the results of a *fit-maximization* problem (see Kydland and Prescott, 1996). The second approach aims at mapping the structural parameters of the theoretical model with the reduced form parameters of an empirical counterpart (represented by a VAR model). This second technique, which has been developed and refined by Del Negro and Schorfheide (2004, 2006, 2008), is the most widely used in modern DSGE models. In a nutshell, it allows one to adopt the DSGE model in order to form prior distributions of the parameter of the VAR. An hyper-parameter $\lambda \in [0, +\infty)$ allows the estimation of a mixed DSGE-VAR model which is then used to evaluate the restrictions imposed on the model: if the optimal value of λ tends to infinity ($\hat{\lambda} \to +\infty$), the model is perfectly able to describe the data, while if it tends to zero ($\hat{\lambda} \to 0$), the model is instead outperformed

[2] For general treatments of ABMs and for discussions about their similarities and differences with DSGE models we refer the reader to Fagiolo and Roventini (2017), Farmer and Foley (2009), Gaffard and Napoletano (2012), Guerini et al. (2016), Kirman (2016), LeBaron and Tesfatsion (2008), Lengnick and Wohltmann (2013).

[3] At the root of this underdetermination problem is the fact that while causal relationships are in general asymmetric, statistical relationships are in general symmetric.