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Emiliano Alvarez (Universidad de la República)

Volker Grimm (Helmholtz Centre for Environmental Research-UFZ)

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The added value of using the ODD Protocol for agent-based modelling in Economics: go for it!

Emiliano Álvarez[1] and Volker Grimm[2]

[1] Universidad de la República,
FCEA, Department of Quantitative Methods
Montevideo, 11200, Uruguay
emiliano.alvarez@fcea.edu.uy
[2] Helmholtz Centre for Environmental Research – UFZ,
Department of Ecological Modelling, Permoserstraße 15,
Leipzig, 04318, Germany
volker.grimm@ufz.de

Abstract. Agent-based modeling (ABM) is a modeling tool that has increased its use in different sciences as well as in economics. Among other reasons, this is due to the extension of the complex systems paradigm in different sciences and the increase in multidisciplinary work. This phenomenon manifests itself in the social sciences from the realization that social organizations are interactive systems of multiple agents, with feedback, reflexivity, and non-linear effects on the rest of the system. The way in which information is structured is conditional on the paradigms applied and the problem addressed. Since economies are assumed to be complex adaptive systems, theories and their representations must be consistent with this principle. Therefore, their modeling must allow for a faithful representation of the problem under analysis while being clear and allowing for analysis and subsequent replication.
In this paper, we demonstrate how the ODD (Overview, Design concepts, and Details) Protocol fosters transparency and coherence for economic ABMs. To do so, three published ABMs from economics are taken, analyzing the structure and content of their descriptions, and rewritten according to ODD. It discusses in particular the added value of using ODD and how all this could help to overcome different obstacles to a wider use of Complex Systems and ODD in Economics identified in the preceding literature.

Keywords: ODD protocol, Economics, agent-based model, macroeconomics, Schelling model

1 Introduction

Agent-based models (ABMs) have become increasingly popular in different disciplines in recent decades, as evidenced by the number of articles in various

journals, including Economics[3]. The Santa Fe Institute has played a key role in promoting the use of ABMs in Economics, which can be seen in the emergence of "The Economy as an Evolving Complex System" (Anderson et al., 1988) as a result of the coordinated action of economists such as Kenneth Arrow, together with specialists in Complex Systems from other disciplines.

ABMs are used to address questions that cannot be effectively tackled using other approaches. They take into account agency, heterogeneity, local interactions, adaptive behavior, and emergence, which are crucial for many economic problems[4]. These bottom-up models complement the top-down models that are based on aggregation and averaging, which are common in the economic discipline. ABMs complement top-down models, which are useful for understanding the economy as a whole, but they do not capture the dynamics and heterogeneity of individual agents and their interactions. Therefore, bottom-up ABMs can provide complementary information and enable a deeper and more detailed understanding of economic processes.

ABMs have been used extensively in Economics to model the dynamics of markets, price formation, competition, policy impacts, and other topics (Zehra and Urooj, 2022). ABMs are particularly useful for modeling situations in which individual agents have adaptive behaviors and make decisions based on their environment and available information (Müller et al., 2013). In general, ABMs are especially useful for addressing questions that cannot be effectively answered with other approaches. These models allow for the consideration of the heterogeneity and interaction among agents at the local level, as well as the emergence of global patterns that can arise from the interaction of individual agents (Epstein and Axtell, 1996; Tesfatsion, 2006). ABMs are particularly useful for understanding complex systems that involve agency, heterogeneity, and adaptive behavior, as well as local interactions (Bonabeau, 2002).

The Overview, Design concepts, and Details (ODD) protocol is a widely recognized framework for describing the essential components and assumptions of ABMs (Grimm et al., 2006). The protocol provides a standardized way of documenting model design, facilitating transparency, and reproducibility (Grimm et al., 2010). It can be used to help understand how different economic processes interact with each other and how changes in one area can affect others. For example, changes in the labour market, such as wage increases or job losses, can lead to changes in demand for products, which in turn can affect supply, prices and other economic variables. The ODD protocol can help to identify and analyze these relationships, allowing for better predictions of how economic systems may change in the future.

[3] This pattern can be seen in Chen et al. (2011) and the evolution of ABMs in Economics in Bargigli and Tedeschi (2013); Zehra and Urooj (2022); Segovia et al. (2022).

[4] For instance, from the seminal article "More is different..." (Anderson, 1972), to Dosi and Roventini (2019), which is a clear reference to the previous one, highlighting the aspects by which macroeconomics should be studied according to this paradigm.

The structure of the article is as follows. First, a brief description of the ODD protocol and its underlying rationale will be provided. Second, we will show how the ODD protocol can improve the transparency and coherence of ABMs in Economics by selecting three published ABMs, analyzing the structure and content of their descriptions, and rewriting them using the ODD protocol. Next, we will discuss the key takeaways from this demonstration, including the benefits of using the ODD protocol and how it can help to overcome various obstacles to its wider adoption in economics, as identified by Alvarez et al. (2021). Finally, we provide specific recommendations for ABM developers in Economics on how to implement the ODD protocol in their modeling practices; in addition, we will discuss how the various levels of reasoning (of the agents in the model and their assumptions, derived from the researcher's assumptions) can be applicable to the field of Economics and what additional information might need to be included in the description of the model.

2 ODD

In the early stages of ABM development, models were often designed in an ad hoc manner and lacked transparency (Grimm et al., 2006). There was also limited analysis of the models themselves, which led to concerns about the reliability and validity of the results (Wilensky and Rand, 2007). However, ABM has matured significantly over the last two decades, with the development of standardized modeling protocols such as the ODD (Overview, Design concepts, and Details) protocol (Grimm et al., 2006). The ODD protocol provides a framework for describing the components of an ABM and its underlying assumptions, making it easier to understand and replicate models (Grimm et al., 2010). Its first version was published in 2006, which has received updates in 2010 (Grimm et al., 2010) and 2020 (Grimm et al., 2020).

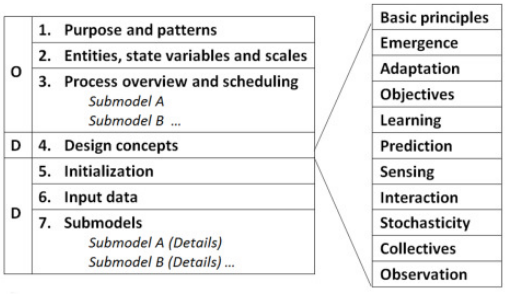

Fig. 1. Structure of the model, following the ODD protocol. Source: Grimm et al. (2020).

Figure 1 depicts a schematic of this protocol, whose components can be described as follows:

1. Purpose and patterns: This element describes the overall goal of the model and the patterns of behavior that it is intended to capture. It includes a statement of the research question or hypothesis that the model is designed to address, as well as a description of the key processes, feedback, and emergent phenomena that the model is intended to simulate.
2. Entities, state variables, and scales: This element describes the key entities (i.e., agents) that the model represents, the state variables that describe the properties and behavior of these entities, and the scales at which these entities and variables operate. It also describes any spatial or temporal dimensions that are relevant to the model.
3. Process overview and scheduling: This element describes the sequence of events and actions that occur in the model, as well as the timing and frequency of these events. It includes a description of the main processes that are simulated by the model, as well as any interactions or feedback between these processes.
4. Design concepts: This element describes the fundamental design concepts and principles that underlie the model. It includes a description of the rules, algorithms, and decision-making mechanisms that govern the behavior of the agents in the model, as well as any other design considerations that are relevant to the model.
5. Initialization: This element describes the initial conditions and parameters that are set for the model at the start of the simulation. It includes a description of how the initial state of the model is determined, as well as any assumptions or uncertainties that are associated with the initial conditions.
6. Input data: This element describes the sources and types of data that are used to parameterize and validate the model. It includes a description of the data sources, as well as any preprocessing or calibration steps that are required to prepare the data for use in the model.
7. Submodels: This element describes any submodels or modules that are included in the model. It includes a description of how these submodels interact with the main model, as well as any assumptions or limitations that are associated with the use of these submodels.

Despite its many advantages, the use of ODD in Economics is still relatively low compared to other fields that employ ABMs (see Alvarez et al. (2021), and the comparison with other fields in Janssen et al. (2020)). Authors suggest several reasons for this. One reason is that many economists lack familiarity with ABMs and the ODD protocol, and may be more comfortable with traditional modeling approaches. Another reason is that Economics has been slower to adopt ABMs than other disciplines, meaning there is less established practice in using the ODD protocol.

However, there are compelling reasons for economists to embrace the ODD protocol in their modeling practices. One key advantage of using the ODD protocol is that it allows researchers to clearly articulate the assumptions and structure

of their models, which can improve transparency and help others to understand and critique the model (Alvarez et al., 2021). This is particularly important in Economics, where models can be complex and abstract, making it challenging for others to replicate or understand the findings. This can lead to more realistic and useful models (Grimm et al., 2006) that better capture the dynamics of real-world economic systems.

However, some authors have expressed that the use of this protocol to describe interactions between humans requires some adjustments. For example, in (Polhill et al., 2008, p. 3) is considered that *"It remains, however, an open question whether the Design Concepts, a part of the ODD protocol formulated for organisms (e.g., fitness, adaptation, sensing), can also be applied to human agents and problems from the social sciences"*. Müller et al. (2013) adopts this notion, recognizing that the *agents* in the model make decisions based on mental processes' meta-models. This is significant in economics, as the heterogeneity of individuals is also influenced by their vision (or information processing) of the surrounding world. Individual decision-making must be modeled using not only technological, but also cognitive, informational, social, and cultural factors.

In the following section, highly relevant models are analyzed, including Ashraf et al. (2017), Delli Gatti et al. (2011), and Dosi et al. (2010). These are relatively simple models, but they have served as the foundation for the vast majority of subsequent ABM development in economics.

3 ODDing three ABMs from Economics

Here, following the example of Polhill et al. (2008), a short overview is given of some very relevant articles in complex system in economics, particularly macroeconomic models. This is interesting because in these models the different sectors of the economy can be observed in action interacting with each other (a tradition that in Economics began in the 18th century, from Quesnay's *Tableau Economique*[5]).

These three models, however, analyze different aspects of the economy, as we will see below. While in Ashraf et al. (2017) the focus is on the banking system (another example can be found in Chan-Lau (2017)), the following models (Delli Gatti et al., 2011; Dosi et al., 2010) analyze the problem of technical change, economic growth and business cycles. For each of them, a brief mention of the model is made (following the ODD protocol), together with some aspects of the description that are not found in the model.

3.1 An economy with bank structure: Ashraf et al. (2017)

Overview:
The article develops an agent-based computational model to examine the impact

[5] Ideas about the interaction between local entities are present in this representation, as stated by (Schumpeter, 1955, p. 233): *"Quesnay had this conception of the general interdependence of all sectors and all elements of the economic process in which ... nothing stands alone and all things hang together"*.

of bank market organization on macroeconomic performance. Specifically, the model explores how the structure of the banking sector affects the stability and efficiency of the system, acting as a "financial stabilizer" or the economy.

Purpose: The purpose of the study is to evaluate the effects of different market structures in the banking sector on the macroeconomic performance of an economy.

Entities, State Variables, and Scales: The entities in the model are banks, firms, households and government. The state variables include the level of bank lending, the level of output, the level of inflation, and the number of banks in the market. The scales of the model are at the macroeconomic level, with the model examining the interactions between the various entities and state variables.

Process Overview and Scheduling: The model is an iterative process where each time step represents one week. At each time step, banks make lending decisions based on their profitability and level of risk, while households and firms make investment and consumption decisions. The model is stochastic, with some parameters being drawn from distributions, such as the distribution of bank profitability.

The model briefly presented here (only its *Overview*) allows us to understand, in general terms, the fundamental ideas of the model. This model does not specify the space where the actions take place, while the temporal sequences are considered. In line with Müller et al. (2013), fundamental issues about the decision making of individuals in the model, such as individual sensing, individual prediction and stochasticity, are not noted. There is also a lack of a better description of the submodels that arise from the schedule.

3.2 Macroeconomics from the bottom up[6] (Gatti et al., 2011)

Overview:
This model, developed in the book Gatti et al. (2011), presents a description of macroeconomic agent-based computational modeling (ABM) techniques. The model aims to provide a bottom-up approach to macroeconomic analysis by simulating the interactions between individual agents in the economy.

Purpose: The purpose of the model is to provide an alternative to traditional macroeconomic models by emphasizing the importance of individual behavior and heterogeneity in the economy. The model also aims to provide insights into macroeconomic phenomena such as business cycles, inflation, and growth.

Entities, State Variables, and Scales: The entities in the model include households, firms, banks, and the government. The state variables include income, consumption, investment, employment, inflation, and interest rates. The scales of the model are at the macroeconomic level, with the model examining the interactions between the various entities and state variables.

Process Overview and Scheduling: The model is an iterative process where each time step represents one quarter of a year. At each time step, households

[6] A full description of this model, applying the ODD protocol, can be found at Platas-López et al. (2019).

make consumption and savings decisions based on their income and preferences, while firms make investment and hiring decisions based on their profitability and demand for goods. Banks make lending decisions based on their capital position and the creditworthiness of borrowers. The government makes policy decisions such as setting interest rates and taxation levels.

This model has a further development, even with an emphasis on the subsequent validation of the model. Even in a relatively simple model, more extension may be needed for a detailed description (Grimm et al., 2020)[7]. In this book, there are specific sections for each submodel[8]. However, we found that there is no significant development of stochasticity or individual prediction, while it is not appreciated that individuals have learning. The assumptions of the model are presented, where the applied theoretical framework is clearly explained.

3.3 Schumpeter meeting Keynes (Dosi et al., 2010)

Overview:
The article presents an agent-based model of endogenous growth and business cycles that combines the ideas of Schumpeter (technological progress) and Keynes (a Keynesian economy). The model aims to provide insights into the effects of different policy interventions on macroeconomic outcomes.

Purpose: The purpose of the model is to explore the interactions between innovation, finance, and macroeconomic outcomes such as growth and business cycles. The model also aims to evaluate the effectiveness of different policy interventions in promoting long-term growth and stabilizing the economy.

Entities, State Variables, and Scales: The entities in the model include firms, banks, households, and the government. The state variables include capital, labor, innovation, consumption, investment, interest rates, and inflation. The scales of the model are at the macroeconomic level, with the model examining the interactions between the various entities and state variables.

Process Overview and Scheduling: The model is an iterative process where each time step represents one quarter of a year. At each time step, firms make production and investment decisions based on their profitability and the level of innovation in the economy. Banks make lending decisions based on their capital position and the creditworthiness of borrowers. Households make consumption and savings decisions based on their income and preferences. The government makes policy decisions such as setting interest rates and taxation levels.

As in previous instances, it is possible to describe the model based on the sequence of events and not the actions of the agents or submodels. The model contains stochastic elements as well as a number of elements related to individual decisions. Nonetheless, it is in the (individual) decision-making section where the interaction and collectives, as well as the emerging processes, are not clearly established.

[7] For slightly more "complex" models, as mentioned in Grimm et al. (2020), *"ODDs are longer than 30-40 pages and often have submodels which by themselves require 10 or more pages"*.

[8] See (Delli Gatti et al., 2011, Ch. 3).

In the three articles that supplement the text description, schematics, the code (or a pseudo-code), and many of the model's most important equations are presented. As noted in Alvarez et al. (2021), this has its origins in the way models are typically presented; however, improvements in the description and a greater emphasis on the description of individual behaviors and instances of interrelations between the individual and the aggregate could be beneficial.

As can be seen, the problem is not in the Overview; most of the models are very clear on this. The biggest problem (and one that can be improved with this approach) is making all the design details and sub-models (even "mental" models) explicit. This protocol allows us an *organized* way to do it.

4 Discussion and conclusions

Agent-based modeling is a powerful tool for understanding complex systems, and its use has become increasingly widespread in economics and other fields. The development of standardized protocols such as the ODD protocol has helped to improve the reliability of ABMs, enabling researchers to study a wide range of phenomena in new and innovative ways. While the use of ODD in economics is currently lower than in other fields, there are compelling reasons for economists to embrace the protocol. By making it easier to document and understand ABMs, the ODD protocol can improve transparency and reproducibility, and help economists design more accurate and useful models.

It is interesting to note that, although there are multiple reasons for using a standardized protocol to describe models, certain points in the model description may need to be reformulated or interpreted to make them more useful or interesting. Specifically for the purpose of making comparisons to other models (whether they are ABM or not). In the case of Economic ABMs, decisions are made by individuals or organizations led by them, who are susceptible to the inherent biases of their human condition (Gigerenzer and Gaissmaier, 2011; Kahneman et al., 1982). In this sense, it is relevant to adopt several of the points reviewed by Müller et al. (2013), who sought to improve the description in these points. It is essential to note that, whether consciously or unconsciously, economic models are framed within a particular economic theory with specific assumptions. This distinction, which is important when considering and analyzing ABM in Economics, is not specifically mentioned in the standard description, but it is suggested in Müller et al. (2013). Specifically, taking into account that heterogeneity can be determined by the existence of differences between individuals' meta-models. In the case of economic models, it would be desirable to include the theoretical framework associated with agent's meta-models.

Within articles in Economics, there is usually a space for "policy recommendations", based on previous results. There is a very interesting and in-depth current discussion (see, among others, Fagiolo and Roventini (2017); Edmonds et al. (2019); Poledna et al. (2023)) about the convenience of applying this type of model to the design and evaluation of public policies, and its potential compared to Dynamic Stochastic General Equilibrium (DSGE) models. It would

be of great value to obtain a synthesis of the policy recommendations resulting from the model, which in turn are strongly related to the paradigm chosen by the researcher.

From the presentation of the previous sections, it can be verified that ODD is flexible enough to be easily adapted to the description of economic models. In ad-hoc descriptions, it is notorious that aspects of the agents' decisions, as well as the model's schedule, can be uncertain in some cases. Economic ABM attempts to mitigate this shortcoming with other tools, such as diagrams or pseudo-code[9]. In order to advance the replication and validation of ABMs, and even for their use when making forecasts, more efforts should be devoted to making ABMs more "transparent". One way to do this is via the use of protocols like the one mentioned.

[9] An analysis of the use of these tools can be found in Janssen et al. (2020) and Alvarez et al. (2021).

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