Agricultural Systems 164 (2018) 95–106

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Review

A review of Agent Based Modeling for agricultural policy evaluation

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ARTICLE INFO

Keywords:
Agent Based Modeling
ABM
Agricultural policy
Systematic review

ABSTRACT

Farm level scale policy analysis is receiving increased attention due to a changing agricultural policy orientation. Agent based models (ABM) are farm level models that have appeared in the end of 1990's, having several differences from traditional farm level models, like the consideration of interactions between farms, the way markets are simulated, the inclusion of agents' bounded rationality, behavioral heterogeneity, etc. Considering the potential of ABMs to complement existing farm level models and that they are a relatively recent approach with a growing demand for new models and modelers, we perform a systematic literature review to (a) consolidate in a consistent and transparent way the literature status on policy evaluation ABMs; (b) examine the status of the literature regarding model transparency; the modeling of the agents' decision processes; and the creation of the initial population.

1. Introduction

Agricultural policies are moving away from market intervention measures toward a combination of voluntary and compulsory aids on top of basic flat rate support measures related to farm features, its environmental performance and capacity to provide ecosystem services. Consequently impacts of policy measures depend on the specific farm characteristics. So getting insights at disaggregated level and spatial scale becomes relevant for both policymakers and researchers; consequently farm scale policy analysis is receiving increased attention (Langrell et al., 2013).

Berger and Troost (2014) summarized the requirements that farm-scale models need to fulfill in order to provide useful insights within this new policy context: sufficient detail of farm management and agronomic conditions; model the heterogeneity in behavioral constraints and behaviors; include farm interactions; incorporate spatial dimension; consider farm-environment interactions and feedback; move from a comparative-static to a comparative-dynamic analysis; moderate data requirements connected to existing data sources; employ comprehensive sensitivity and uncertainty analysis. They conclude that ABMs have the potential to meet the above requirements and thus can complement existing simulation approaches.

Also, in a recent review paper, Reidsma et al. (2018) examined the development and use of farm models for policy impact assessment. Agent Based models (ABM), about 15% of all 184 papers considered, were found to have the potential to provide important additions to farm level mathematical programming models.

Agent based models in agricultural economics have appeared in the end of 1990's. Some of the early adopters were the CORMAS group which employed a multi-agent approach to study renewable source management within an agricultural systems context (Bousquet et al., 1998). Balmann (1997) used a cellular automata approach for modeling structural change of agricultural production systems; and Berger (2001) used a spatial multi-agent programming model to assess policy options in the diffusion of innovations and resource use changes. The latter two approaches, which were policy evaluation oriented, can be considered descendants of the recursive mathematical programming (MP) approach, as the initial ABMs included a typical MP production/investment problem coupled with a land market module that was solved iteratively. The innovative elements were: the ability to include farms' interaction and in this way to evaluate the direction of the structural change (farm growth/shrinking, farm entry/exit) and the explicit consideration of the spatial dimension.

The additions of ABMs to traditional farm level microeconomic

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https://doi.org/10.1016/j.agsy.2018.03.010
Received 9 October 2017; Received in revised form 18 March 2018; Accepted 26 March 2018

models,[1] in the conceptual level, are well summarized in Nolan et al. (2009) and are shown in Fig. 1. Farm and consumer heterogeneity, spatial location and the consideration of interactions between farms and/or consumers (social networks, land markets, imitation, etc.) are presented as a distinctive feature of ABMs. Moreover in the case of traditional farm models, market outcome is the combination of the aggregate supply and demand functions while in the ABM case, market is simulated by means of individual transactions. Additionally, although traditional farm level models can potentially do so, Nolan et al. (2009) note that since ABM is most often used in cases where equilibrium conditions either cannot be identified or analytically solved, they generally relax the assumption of full rationality. This allows the assumption that economic agents facing limited information and/or information processing capacity and finite resources. Furthermore they can be endowed with adaptive mechanisms and learning capabilities.

In a 2007 review, Matthews et al. note that "there is an increasing pressure from funding agencies to develop (Agent Based Land Use Models) tools that are of practical use by end-users and other stakeholders". Later in a methodological overview of agricultural and farm level modeling development and implementation, Langrell et al. (2013) found that although there is a substantial increase of ABMs models over time, "a large number of existing farm level models are developed for specific purposes and locations and are not easily adaptable and reusable (for policy evaluation)".

Thus, considering the potential of ABMs to complement existing farm level models and that they are a relatively recent approach with a growing demand for new models and modelers, the aims of the paper are twofold: (a) to consolidate in a consistent and transparent way the literature status on ex-ante policy evaluation ABMs; (b) to examine the critical aspects to gain more acceptance from the wider farm modeling community.

Both targets of the paper are pursued by employing a systematic literature review (SLR) approach, for related publications since 2000. The remainder of the paper is organized as follows. Section 2 describes the SLR method used in this study. Section 3 presents the results of the SLR and the discussion of the findings; Section 4 concludes the paper.

2. Literature review design

2.1. Review protocol

The first step of the review protocol is to develop a transparent search strategy for discovering papers that are potentially related to ABM applications in the agricultural policy evaluation domain. Selection criteria are used to classify papers in groups. This addresses the first target of the paper, i.e. a consolidation of the existing ABM policy literature.

Then we clearly and explicitly specify research questions related to the second aim of the paper; an examination of the most critical aspects for further adoption of empirical ABMs from farm modelers. We use a structured process to extract all information needed to address the review questions in a meaningful way.

2.2. Search strategy and selection criteria

Search is confined to papers written in English and published in peer-reviewed journals between 2000 and 2016 and either in title, abstract or keywords include one or more of "agent-based", "agent based", "abm", "multi-agent" or "multi agent" and any word beginning from "polic" and in title any word beginning from "farm", "agricul", "biodivers" or "crop". This is equivalent to the following SCOPUS search command:

> SRCTYPE (j) AND (TITLE-ABS-KEY ("agent-based" OR "agent based" OR "abm" OR "multi-agent" OR "multi agent") AND (TITLE-ABS-KEY (polic*) OR INDEXTERMS(polic*)) AND (TITLE-ABS-KEY (farm*) OR TITLE-ABS-KEY (agricul*) OR TITLE-ABS-KEY (biodivers*) OR TITLE-ABS-KEY (crop*))) AND (PUBYEAR > 1999) AND (PUBYEAR < 2017) AND LANGUAGE (english)

The search produced 176 documents that were further refined based on the criteria detailed below:

Criterion 1: the relevance to the Agent Based Modeling (criterion 1a) and Agriculture domain (criterion 1b). Based on abstract inspection and on full text inspection when necessary we removed 11 papers that were not agent based models but rather were just mentioning the term (NOT ABM). We removed 5 papers where ABM was a fraction of a larger model and thus there were not many details on the ABM implementation (PARTIALLY ABM). We removed 29 papers that were dealing with marine or coastal areas, urban areas, etc., and thus were irrelevant to agriculture (NOT AGRICULTURE).

Criterion 2: *the focus to agricultural policy evaluation subject*. We consider a paper to be relevant if the agricultural policy is a key component of the model that directly affects the model outcome and consequently the paper focuses on the relation of the policy to the model outcome. We included papers which attempted an ex-ante evaluation of a specific policy or evaluated at two or more alternative agricultural policies or different components of a single policy. Based on abstract inspection and on full text inspection when necessary, we removed 72 items and came down to 59 papers that were ABM for agricultural policy evaluation.

Criterion 3: the granularity of the agent. We identified two distinct categories, with different methodological issues. The first uses agents to represent individual farms and the second assigns them to aggregated entities, e.g. representative farms, regions, etc., or non-farm entities like landscape cells, animal or plant agents, etc. We selected to deal only with individual farm models. Based on full text inspection, we removed 8 papers.

Criterion 4: Regarding the questions that are addressed. We distinguish between data-driven models and theory-driven models, following Barlas (1996) and Polhill et al. (2013). Data-driven models focus on reproducing real world situations and thus are driven and validated by collected data and evidence. In the second category the models are based on qualitative information and second order data (stylized facts) and are used for exploring questions in principle, e.g. looking for emerging properties like resilience, etc. Ex-ante policy evaluation is pursued by means of farm models that simulate an actual farming system (Reidsma et al., 2018; Langrell et al., 2013). Due to the empirical policy orientation of the paper, we focus on data-driven ABM. We thus proceed with the data-driven (empirical) individual-farm ABM excluding 19 papers that were individual farm theory driven ABM policy evaluation papers.

An overview of the refinement process is in Fig. 2 and a detailed correspondence of criteria to publications, can be found in the excel supplement.

Thus we conclude to 32 empirical-based and individual-farm relevant papers published between 2000 and 2016 as in Table 1. In Fig. 3 we depict the temporal evolution of the various recognized categories. The agriculture-related ABMs (greens) are constantly increasing from 2005 and onwards and the same happens for agricultural policy evaluation ABMs (dark greens).

[1] Farm type models are originally built by means of mathematical programming, econometric modeling or simulation techniques. Due to suitability to investigate novel policy instruments (advantage over econometric models) and their time and cost efficiency (comparing with simulation models) mathematical programming in various forms (LP. NLP, MILP) prevailed to the others. When we mention throughout the text the term "traditional models" for agricultural policy analysis, we refer to the above three categories, most often though in MP models. On the other hand, combined econometric-mathematical programming models as well as ABMs or ABMs combined with mathematical programming modules are novel approaches still in the making.