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Evaluating the role of behavioral factors and practical constraints in the performance of an agent-based model of farmer decision making

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ABSTRACT

Farmer decision making models often focus on the behavioral assumptions in the representation of the decision making, applying bounded rationality theory to shift away from the generally criticized profit maximizer approach. Although complex on the behavioral side, such representations are usually simplistic with respect to the available choice options in farmer decision making and practical constraints related to farming decisions. To ascertain the relevance of modeling different facets of farmer decision making, we developed an agent-based model of farmer decision making on crop choice, fertilizer and pesticide usage using an existing economic farm optimization model. We then gradually modified the model to include practical agronomic constraints and assumptions reflecting bounded rationality, and assessed the explanatory power of the added model components. The assessments were based on comparisons to the real world data and to the results of the previous model stages, and included two model versions differing with assumptions on the farmers' rationality. Thus, we assessed the sensitivity of the model to its behavioral assumptions. The results indicated that contrary to expectations, implementation of the practical constraints improved the model performance more than the modifications in the behavioral assumptions.

1. Introduction

Agri-environmental policies are developed to influence environment through farmers' actions. However, such policies are often ineffective and result in unintended consequences (Malawska et al., 2014). Modeling farmers' decision making on land-use can increase the effectiveness of these policies by providing insights into possible outcomes of specific regulations. In particular, models that can grasp the complexity and heterogeneity of farmer decision making are needed. Agent-based modeling has been widely used for that purpose since it is well suited for representing individual human behavior (Filatova et al., 2013).

Farmer decision making agent-based models (ABMs) use various approaches to represent human decision making, including two opposing theories on rationality of decision makers, i.e. perfect rationality and bounded rationality (Simon, 1955). While the decision making representations based on full rationality assume agents maximize utility which is mostly confined to economic value, the representations based on bounded rationality vary with respect to behavioral assumptions (An, 2012; Parker et al., 2003) and might be subjective (Janssen et al., 2006). Therefore, such assumptions can be a source of uncertainty in a model (Hare and Pahl-Wostl, 2001; Holtz and Nebel, 2014), and the specification of farmer decision making might be decisive for model outcomes. Thus, it is important to assess if the assumptions related to agent rationality and specific implementations in case of bounded rationality have a strong impact on model outcomes. The sensitivity of models using alternative decision making specifications should be tested (Filatova et al., 2013); more specifically, a comparative analysis of the model under different specifications of agent rationalities should be performed (Holtz and Nebel, 2014).

Another means of assessing the robustness of the behavioral assumptions representing the bounded rationality theory is a comparison of the 'traditional' model, assuming rational agents, with a corresponding model implementing boundedly rational agents (Holtz and Nebel, 2014). However, studies that focus on the comparison between different rationalities/decision making specifications in agri-environmental models are not common. Lindgren and Elmquist (2005) use four classical models of decision-making that represent different levels of knowledge, i.e. rational, bounded rational, incremental and pure chance driven decision maker. Jager et al. (1999) carried out a test of different behavioral rules in the Consumat approach where agents are equipped with different decision strategies. The authors showed that assumptions about which behavioral strategies agents engage in will determine the macro-level outcomes of the models. Holtz and Nebel (2014) compared two models with different farmer rationality, i.e. rational utility maximizer versus satisficing approach based on the bounded rationality theory. All of these studies find that the specification of agent rules of behavior significantly affects model results. Thus, such tests appear to be an important part of model assessment.

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Here we present a farmer decision making ABM able to represent both a detailed, empirical data-based profit maximization as well as other decision making strategies and farmer types based on goals. The model was developed in a staged-based procedure from an existing model based on microeconomic optimization. Such model development, i.e. starting with an economic model as a base and introducing gradual changes, enables assessment of each change in the model specification. In particular, developing a model by adding additional factors one at a time allows testing if the added factor changes model outcomes significantly, and thus, if it can be ignored (Edmonds, 2012). Since the model development included the change in the agents' rationality, it was possible to compare two versions of the model: first assuming perfectly rational profit maximizers, and second, assuming boundedly rational agents.

The aim of this study is to ascertain how the modifications introduced in the model including changes in practical/agronomic constraints and in the behavioral assumptions affected the model dynamics and its outcomes, i.e. if they actually improved the model performance. Moreover, the goal was to compare the relative impact of the different types of factors added at subsequent model development stages. This was tested by assessing each development stage in terms of their ability to reproduce real world data on crop composition, fertilizer and pesticide usage in the modeled region, and by performing a sensitivity analysis on the final model version.

In the next section we present the general modeling strategy. This is followed by a description of changes introduced at each stage of the model development and the reasoning behind the modifications. Next, we present the results of the assessment of the model development stages, and discuss them in the context of the model's design, limitations and applicability to policy impact assessment. We conclude with general recommendations for designing fine scale farmer decision making ABMs.

2. Modeling goals and strategy

One of the strategies for creating decision making models is further development of an existing model. This is in accordance with the TAPAS (Take A Previous model and Add Something) approach suggested by Frenken (2006), who argues that models developed using incremental modeling strategies are faster to build, easier to communicate, and thus, easier for others to understand. We therefore used an existing microeconomic optimization model (Fonnesbech-Wulff et al., 2010) to develop a farmer decision making model on crop choice, fertilizer and pesticide usage. However, the existing model had two major limitations. First, it used static observed data on crop distribution from the real world in one year to specify restrictions on minimum and maximum allowed crop areas. This 'artificially' limits output space, i.e. the range of possible outcomes of the model. Second, decision makers are assumed to be perfectly rational profit maximizers even though it has been argued that such a representation of human behavior is not realistic (Conlisk, 1996; Edwards-Jones, 2006; Gasson, 1973; Simon, 1955). This has also been demonstrated in empirical studies (Cyert and March, 1963; Kahneman et al., 1982; Madsen, 2003; Nielsen, 2009).

One of the modeling strategies that facilitate the implementation of decision making not based on economic optimization is agent-based modeling. However, in comprehensive farmer decision making modeling, i.e. including a wide range of decisions, the maximizing approach is prevalent (Malawska et al., 2014) (e.g. Kellermann et al., 2008; Lobianco and Esposti, 2010; Schreinemachers and Berger, 2011). The alternative to this type of farmer decision making models are models with a more behavioral focus, e.g. FEARLUS (Polhill et al., 2010), pampas model (Bert et al., 2011) or several models based on the Consumat approach (Jager et al., 2000) (e.g. Acosta-Michlik and Espaldon, 2008; Dung et al., 2005; Mialhe et al., 2012). In these models, agents are equipped with different decision making strategies, usually chosen depending on the agent's current conditions (e.g. level of satisfaction). The strength of these approaches lies in the acknowledgement that people do not always optimize, but also use other decision making mechanisms. These models include economic consideration in decision making, however, it is relatively simple compared to the microeconomic models, e.g. not based on empirical data (Polhill et al., 2010), or limited to a few choice options (Bert et al., 2011; Dung et al., 2005; Mialhe et al., 2012). None of these models differentiated farmers with respect to their goals/objectives within a single simulation.

Thus, the main goals of the ABM development discussed in this article were (i) to modify the restrictions on minimum and maximum crops areas present in the original microeconomic model, and (ii) to represent decision making based on bounded rationality theory without oversimplifying the economic considerations in the decision algorithm. As a part of achieving these goals we added spatial and temporal dimensions to create a more realistic, and thus, more accurate farmer decision making model.

3. Methods

3.1. Model development stages

The existing microeconomic farm model (Fonnesbech-Wulff et al., 2010), here referred to as a 'farm optimization model' (FOM), used as a starting point in the model development includes decisions at a farm level on crop composition, fertilizer and pesticide usage per crop and is parameterized for a 10 × 10 km area of Bjerringbro in Jutland, Denmark in 2005; which is a source of the real world data here referred to as a baseline. Four farm types are distinguished: pig, cattle, arable and other; each farm has one of three soil types: clay, sandy or other, and is categorized either as a business (>10 ha) or a private (≤10 ha) farm. There are 40 different crops categorized as either cash crops (grown for sales) or fodder crops (used only as a source of fodder for livestock). Additionally, areas of certain crops grown on contracts (e.g. potatoes for industry) are fixed, i.e. their area is constant. Decisions are optimized for each farm with an objective of maximizing profit. A more detailed description of the original model is included in Appendix S1 in Supplementary material.

ABM model development was divided into five main stages: stage 1, base model; stage 2, spatially explicit dynamic ABM; stage 3, model with modified agronomic constraints; stage 4, ABM with modified behavioral assumptions, where stage 4a involved an introduction of farmer types based on goals, and stage 4b involved an introduction of different decision making modes, but no farmer types; stage 5, final model including both farmer types and different decision making modes. In the following sections we list changes and reasoning for introducing them at each stage. For the details of implementation of the modifications see Appendix S2 and model documentation (Malawska, 2014) in Appendix S3.

3.1.1. Stage 1: the base farmer decision making model

The aim here was to port the original model to C++ and into the ALMaSS (Topping et al., 2003) framework as a preparatory stage for developing the agent-based model. This stage involved:

a) reimplementation of the FOM in an object-oriented framework;
b) modification of the optimization method.

The model was developed within an existing ABM system for modeling impacts of land-use on wildlife, ALMaSS (Topping et al., 2003), and was programmed in C++ using Visual Studio 2010 (Anon., 2015).

The FOM used external software to solve the optimization problem in a single step. However, to better represent decision making behavior, the stage 1 optimization method assumed farming problems, such as optimal amount of fertilizer for a given crop, are solved sequentially. The stage 1 simplified optimization algorithm (Fig. 1 and Appendix S2)