Complex Social Systems: Modeling Agents, Learning, and Games
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Coding Project: Crop Wars

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1 Introduction

Agricultural structures are shaped by a variety of factors, including economic, environmental, cultural, technological and geographical conditions [1].
Consequently, both farmers and policymakers can benefit from farm-level models which optimise water usage and crop nature, based on a set of different externalities including water ressources availability and market dynamics.
The model featured in this coding project aims to illustrate the process behind the development of agent-based farm-level models, by starting with a simple, deterministic model that is progressively complexified with elements from physics-based models and game theory.

2 State-of-the-Art

To guide the development of our illustrative model, a literature review was conducted to assess the state-of-the-art on agent-based modelling for water ressources allocation and farming simulations.
Our starting point was the thesis *"Agricultural policies and farm structures: Agent-based modelling and application to EU-policy reform"* by Happe (2004) [1], which outlines in details the development of an agent-based model (AgriPoliS) to assess the influence of agricultural policies at the farm level, which is applied to a case study in the region of Holenhole in Germany.
To have an overview of more recent approaches. a seed review paper was selected, *"A review of Agent Based Modeling for agricultural policy evaluation"* by Kremmydas et al.(2018) [2] from which a literature graph was generated using the online tools Connected Papers, and is analysed on figure 1.
For completeness, the graphs generated through other seed papers were also analysed, including an older paper applying game theory to decision making in farmer cooperatives by Staatz (1983) [3] and a case application of agent-based models to water allocation on the transboundary Nile river by Ding (2016) [4].
One thing which became apparent through our literature review was that the parametrisation of the models with real-life data, calibration and sensitivity analysis, as well as the model validation through the analysis of existing agricultural systems was the most time and ressource-consuming part of the studies. As such, we decided to procedurally generate data related to externalities (crop price and availability, weather data, water ressources availability) and to generate a virtual geography for our agent-based model, centering our study around the construction of the model itself and the analyis of the interactions between agents for a given set of externalities.
A possible extension of this project would be the application to a real-life case study.

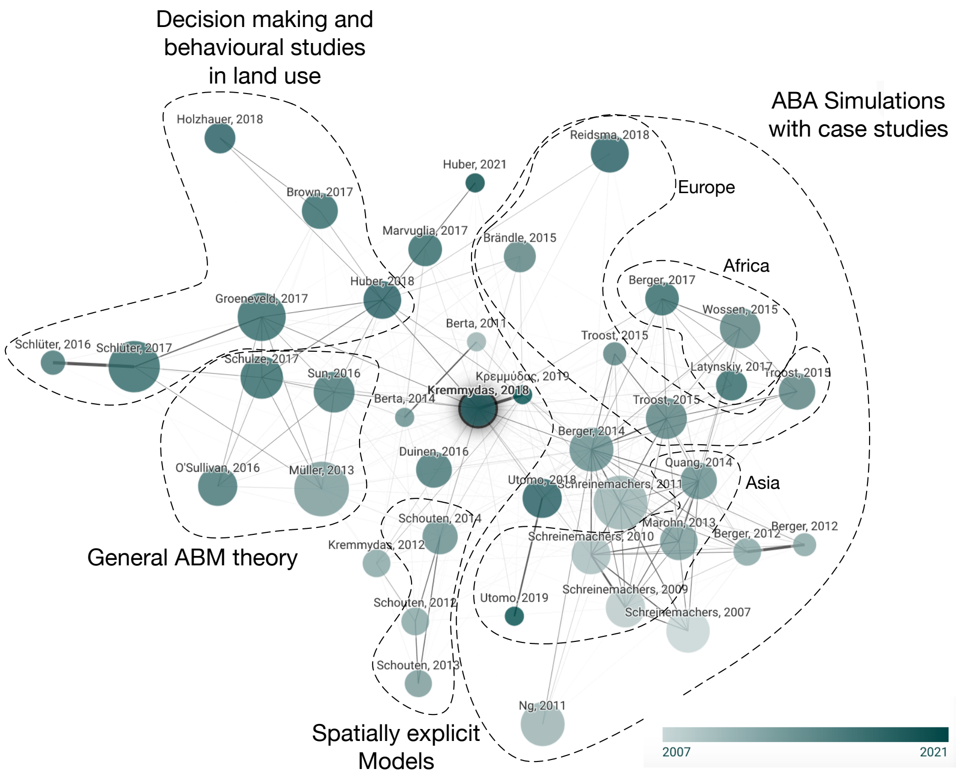

Figure 1: Graph showing papers related to ref. [2] generated on Connected Papers. Circle radius is proportional to number of citation, color to publication date, dashed line refers to paper categories. ABM: agent-based modelling, ABA: agent-based agricultural simulations.

3 The Crop War model

3.1 Software

In order to build the model, we decided to use the python library Agentpy which conveniently introduces the `Agent`, `Grid`, `Model`, and `Experiment` classes, allowing to create our model with minimal pre-requisite work.
The present report was generated via LaTeX, and all relevant programs or documents were hosted on a git repo, with which our team interacted using Visual Studio Code.

3.2 Overview

The Crop War model aims to visualise how farmers can compete with respect to water ressources and crop profitability, given a geogaphical environment (the `Map` class) and a set of externalities including weather conditions, market dynamics (supply and demand impacting the price of crops), variable water ressources and government policies.
At each time step dt, all agents collect their crop yields and are faced with the choice of selling it at market price or stocking it for later use. Agents can also change the crops they are growing, or leave their land idle for replenishment of its nutritive properties, where the respective probabilities of these choices can be influenced by agent personalities.
The wealth W_i of each agent is then plotted as a function of time t, and an analyis is carried out to explain the success rate of different strategies, given a set of externalities such as weather conditions or government policies.

3.3 Model development

In order to illustrate the development of our Crop Wars model, this section is organised in versions, starting from the simple, deterministic v1.0 on top of which we progressively implement new features such as market dynamics, weather events and agent personalities.

3.3.1 Version 1.0

The first version of the model is not spatially resolved, in the sense that each agent can only grow one crop at a time and can not expand to other locations.
The price of each crop is fixed and does not vary as a function of time, and the agents only have the choice between selling or stocking their yields, their storage space being unlimited.
Fig. show the evolution of the budget (in $) and stock as a function of time over 10 time steps for 5 agents choosing between 2 crops to grow:

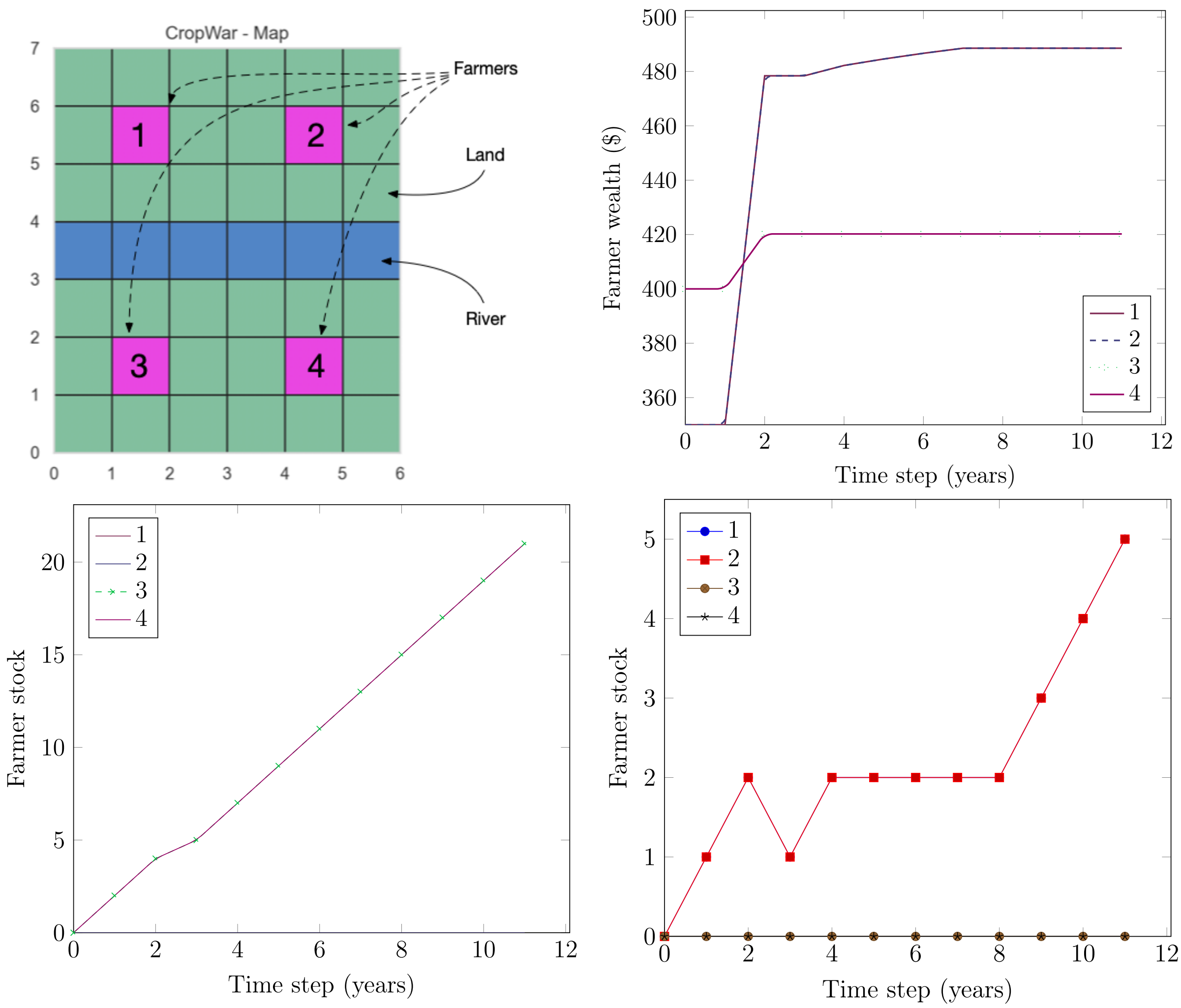

Figure 2: Graph showing the evolution of crop stocks (left) and farmer's budget (right) as a function of time over 10 time steps

3.4 The market model

3.5 Agent strategies

References

[1] K. Happe, ed., *Agricultural policies and farm structures - Agent-based modelling and application to EU-policy reform.* Studies on the Agricultural and Food Sector in Central and Eastern Europe, Volume 30, 2004.

[2] D. Kremmydas, I. N. Athanasiadis, and S. Rozakis, “A review of Agent Based Modeling for agricultural policy evaluation,” *Agricultural Systems*, vol. 164, pp. 95–106, July 2018.

[3] J. M. Staatz, “A game-theoretic analysis of decision making in farmer cooperatives,” *American Journal of Agricultural Economics*, 1983.

[4] N. Ding, R. Erfani, H. Mokhtar, and T. Erfani, “Agent Based Modelling for Water Resource Allocation in the Transboundary Nile River,” *Water*, vol. 8, p. 139, Apr. 2016.