Appendix A: Eastern Snake Plain Farmer Adaptation Model - Version 1 ODD +D

Overview

Purpose

What is the purpose of the study?

The study has two primary goals which will be addressed in consecutive phases. First, the study is intended to examine patterns of adaptation among groundwater farmers in the Eastern Snake Plain Aquifer. Due to the introduction of a new groundwater management agreement, farmers throughout the plain are required to cut an average of 13% of their groundwater use. This has led to the adoption of a variety of new practices and strategies for reducing water use. This model is intended to simulate this adoption and evaluate the success of various strategies, the overall impact on the region, and the long-term sustainability of an Eastern Snake Plain agricultural economy operating with 13% less groundwater. Adaptation and decision-making practices are simulated through the operationalization of three social decision-making theories; the model can be run using any of these three theories, thus allowing for parallel investigation of the first research question with three different theoretical drivers. This, then, lays the groundwork for the second objective and phase. The team seeks to better understand the implications of the adopted decision-making model for the results and conclusions of a modeling effort. To do this, the team will seek to investigate the first research question using all three decision-making models and, in the second phase of the study, compare these results and outcomes to each other. The implementation of three separate, theory-based decision-making mechanisms to govern farmer agent behavior within a fully functional model of an agricultural system allows the study team to investigate the original, applied research question, while also improving the collective understanding of the type of variability introduced when decision-making rules are varied.

For whom is the model designed?

The model is designed for use by researchers and practitioners interested in agriculture in the Eastern Snake Plain and decision-making theory. To this end, the interface is designed to allow for easy investigation of the agricultural and economic inputs and outcome variables, as well as to support a thorough understanding of the operationalization of social science theory.

Entities, state variables, and scales

What kinds of entities are in the model? By what attributes are these entities characterized?

Table 1 – Table of model entities and key descriptors

|  |  |
| --- | --- |
| Entity | Attributes by which entities are characterized |
| Farmers | * + - 1. Farm size       2. Farming history       3. Social connections       4. Geographic location       5. Starting equipment       6. Starting irrigation infrastructure       7. Starting bank balance |
| Agronomists | Attitudes |
| Crop consultants | 1. Attitudes |
| Irrigation vendors | 1. Attitudes |

What are the exogenous factors/drivers of the model?

* Presence/Absence of ESPA Comprehensive Aquifer Management Plan

If applicable, how is space included in the model?

The NetLogo GIS add-in is employed to create realistic, spatially-explicit worlds for the simulation. Shapefiles of each groundwater district are used as inputs to provide the background information necessary.

What are the temporal and spatial resolutions and extents of the model?

Each simulation runs at the scale of one groundwater district, with the number of agents approximating the number of farmers in the district. Simulations runs on the order of years, with the number of years selected by the user at the onset of each simulation.

Process overview and scheduling

What entity does what, and in what order?

Farmers are the only actors with true agency. They proceed through a four-season year, which approximates their real-world schedule.

1. Planning season – traditional: Farmers determine preferred crop, plan for planting that best meets their requirements – may still be revised in adaptation planning. With each crop, farmers calculate their expected water use and analyze various water-saving measures, including more efficient irrigation, less water-intensive crops, and fallowing acres or corners. This is all considered in an overall utility function that uses the selected decision-making theory to approximate a farmer’s decision-making process in light of available information.
2. Planting season: Farmers execute plan developed in planning season. Simulation determines total water use by farmers, yields (AquaCrop), and net revenue.
3. Harvest Season (Reconciliation): Farmers calculate their yield and income and adapt their attitudes based on this year’s outcomes.
4. Offseason: Farmers communicate results with other farmers and with consultants in their social network. Afterwards, consultants speak with their farmer clients about the new attitudes they’ve developed after seeing that year’s performance for a variety of farmers.

Other agents only participate in the offseason section of the model, communicating with farmers and sharing their opinions about each possible crop and irrigation method.

Design concepts

Theoretical and empirical background

Which general concepts, theories, or hypotheses are underlying the model’s design at the system level or at the level(s) of the submodel(s) (apart from the decision model)? What is the link to complexity and the purpose of the model?

The biophysical system in the model is driven by theory and empirical knowledge of irrigated agricultural systems. This includes the use of advanced crop modeling (AquaCrop), observed climate data, and GIS-based geographic referencing. The economic system is also developed using empirical knowledge of the agricultural system in the Eastern Snake Plain. This is primarily underlain by data such as crop budgets from the University of Idaho, extensive data sets available through USDA, and farmer interviews conducted by the modeling team.

On what assumptions is/are the agents’ decision model(s) based?

Agents’ decision models are based on three different social science decision-making theories. These are: Bounded Rationality, Theory of Planned Behavior, and Integrated Agent-Centered Framework. These models are explained in greater detail in Table 2. The user selects which decision model is to be used by the farmers at the beginning of each simulation run.

Why is/are certain decision model(s) chosen?

Table 2 – Decision-making theories employed in model

|  |  |  |
| --- | --- | --- |
| Decision-making theory | Basic description | Explanation for selection |
| Bounded Rationality  (BR) | A derivative of early Homo economicus models of human behavior, bounded rationality owes its roots to the work of Herbert Simon and his interest in the impacts of limited information on human decision-making (Simon, 1955, 1972). Simon was the first to argue that rationality was context-dependent and that even utility-maximizing decisions in a world of limited knowledge and limited cognitive capacity could be ultimately irrational and/or lead to undesirable outcomes (Klaes & Sent, 2005). Since then, bounded rationality has become a cornerstone of most models of human behavior; in even the most complex theories of decision-making, bounded rationality is often considered an underlying principle, describing both the limited decision-making space of the actor and the satisficing nature of utility calculations (Simon, 1991). | In agent-based modeling, bounded rationality has served as the default decision-making theory, presenting an easy-to-operationalize step between basic rational choice and advanced social theory (An, 2012). Bounded Rational Actor Theory serves as the “control” framework in this work. |
| Theory of Planned Behavior  (TPB) | Theory of Planned Behavior (TPB) is a social psychological decision-making theory extensively operationalized across the social sciences. This is due in part to its simplicity, a feature that makes TPB a good candidate for operationalization in ABM, as well (Schlüter et al., 2017). First proposed by Icek Ajzen, TPB integrates internal and external factors in decision-making, identifying norms, attitudes, and perceived behavioral control as the central factors in selection of an alternative (Ajzen, 1991). Newer iterations of the theory integrate feedback loops into the system, introducing the opportunity for actors to learn from the results and consequences of their decisions; this learning is characteristic of the shifting decision-making space in adaptive capacity. | The theory was selected for this work because of its preeminent status among scholars of the human dimensions of natural resources (Floress, Akamani, Halvorsen, Kozich, & Davenport, 2015). |
| Integrated Agent-Centered Framework  (IAC) | The Integrative Agent-Centered (IAC) framework was proposed in 2010 as a new way of describing decision-making among farmers in the United States (Giuseppe Feola & Binder, 2010). The work integrates two widely applied theories of decision-making and social systems, Triandis’ Theory of Interpersonal Behavior (1980) and Giddens’ Structuration Theory (1984). IAC framework was developed to draw together the large-scale socially-constructive forces described by Giddens and the small-scale perception-constructive forces of Triandis. | The framework was selected for this work because it was created with both farmer adaptation and modeling operationalization specifically in mind, allowing for minimal reorienting in translation to model rules (Giuseppe Feola & Binder, 2010). |

If the model/a submodel (e.g. the decision model) is based on empirical data, where does the data come from?

This model is supported by a variety of primary and secondary data sources. A complete listing of variables can be found in the codebook, located in the GitHub repository identified earlier in this document. Variable sources, descriptions, and notes on use can also be found in that document.

At which level of aggregation were the data available?

Most demographic data were available at the county level. Using ArcGIS, the original authors determined the approximate composition of each groundwater district in terms of the counties with each district. Using this, the demographics of the groundwater districts were approximated. For future simulations, unless there is a compelling reason to use spatial extent, county (or a collection of counties) is the most straightforward choice for agricultural modeling.

Individual Decision Making

What are the subjects and objects of decision-making? On which level of aggregation is decision-making modeled? Are multiple levels of decision-making included?

Decision-making is modeled at the level of the individual farm and decision-making agents are called “farmers.” Given the demographics of the region and the strong history of family farming, this means that each “farmer” agent could represent any collection of decision-makers operating a farm (e.g. one individual; siblings; father and daughter; etc.). The objects and subjects of decision-making are the assets of each farmer. These include irrigation rights, land for cropping, money in the bank, equipment and equipment characteristics, farmer experience, farmer attitudes, farmer habits, and several other key characteristics. See a more detailed explanation of each algorithm in Chapter 4 of the thesis document which this accompanies[[1]](#footnote-1). Multiple levels of decision-making are represented in the form of varied policy across the groundwater districts – in future iterations, one expected improvement is a simulation capturing all 8 active groundwater districts, which could then include iterative policy decision-making on the part of district policy-makers.

What is the basic rationality behind agents’ decision-making in the model? Do agents pursue an explicit objective or have other success criteria?

Agents pursue the maximization of a utility function which varies between the decision-making models. This utility function includes economic, social, and environmental components, and each functions is an operationalization of a well-studies decision-making theory with high anticipated relevance in this context.

How do agents make their decisions?

Farmers make a two-part decision once a year for each field they control. They compile a list of all possible land uses and a list of all possible irrigation methods, and they determine which combination of these two maximizes their utility function.

Do the agents adapt their behavior to changing endogenous and exogenous state variables? And if yes, how?

Yes. Agents react to changes in their state variables and to changes in climate and other exogenous variables due to the impacts of these various variables on their utility functions. In all cases, they are boundedly rational, estimating from year-to-year the performance of their farming decisions. These estimates are based on their knowledge of the state of the world around them.

Do social norms or cultural values play a role in the decision-making process?

In TPB and IAC simulations, subjective norms are explicitly included in the decision-making algorithms (TPB: “Subjective Norms”; IAC: “Subjective Culture”).

Do spatial aspects play a role in the decision process?

Spatial aspects indirectly affect the decision process by influencing agents’ social networks. Geography is not explicitly included in decision-making. A future version of the model is expected to include surface water availability as part of the simulation, a feature which would require the model to account for agents’ proximity to surface water when allocating water rights.

Do temporal aspects play a role in the decision process?

Agents are aware that they have a three-year period to pull their average groundwater use below the cap. They are also aware of their cropping history and intended rotation. These are indirect methods by which temporality is incorporated into decision-making rules. More directly, the agents have an internalized acceptable return on investment period, which influences their calculation of the cost of new infrastructure. They also consider profit over the course of several years, meaning that they may be willing to take an up-front loss for a longer-term gain.

To what extent and how is uncertainty included in the agents’ decision rules?

Uncertainty is captured in a variety of ways, intending to replicate the balance between art and science that most farmers attempt to walk in managing their farms.

* Uncertainty in precipitation projections and irrigation effectiveness is introduced through semi-random variation of irrigation schedules. Irrigation schedules are initially generated based on near perfect knowledge of crop needs and rainfall data, but these schedules are made “fuzzy” through the semi-random variation.
* Uncertainty in crop markets is reflected in a “fuzzying” of the farmer’s estimates of crop prices. They use their knowledge of trends and market state to estimate prices at harvest, but these estimates are flawed by a semi-random percentage during calculation.

Learning

Is individual learning included in the decision process? How do individuals change their decision rules over time as consequence of their experience?

Individual learning is represented through the “experience” and “farming history” records kept for each farmer. Farmer learning does NOT impact utility algorithms directly; instead, variables included in that algorithm are updated to reflect expanded expertise for each farmer. Farmers can have experience with two components of the simulation world, crops and irrigation methods. A record of each is kept, which influences their attitudes.

Is collective learning implemented in the model?

Not in its current state. Future iterations may include measures of success of the CAMP, which would then allow for collective learning about and reevaluation of the agreement.

Individual sensing

What endogenous and exogenous state variables are individuals assumed to sense and consider in their decisions? Is the sensing process erroneous?

Reference the codebook available on the GitHub for a complete list of variables, their sources, and the interacting agents.

What state variables of which other individuals can an individual perceive? Is the sensing process erroneous?

Individuals can project crop market and weather trends up to one year ahead. Both of these perceptions are flawed. Agents perceive nothing of other agents directly. Instead, all sharing of information occurs through simulated communication along social networks. Individuals can also perceive any and all information about themselves and about their farm. This is not flawed.

What is the spatial scale of sensing?

Agents project crop markets and weather at the regional level.

Are the mechanisms by which agents obtain information modeled explicitly or are individuals simply assumed to know these variables?

Communication is modeled directly, as the social network is determined within the model.

Are costs for cognition and costs for information gathering included in the model?

No.

Individual prediction

Which data are used by the agent to predict future conditions?

Agents use their knowledge of their past outcomes to project future crop performance. They also use a 5-year memory of crop markets to project the prices available for goods. They rely on external projections of the weather and do not require any historical data.

What internal models are agents assumed to use to estimate future conditions or consequences of their decisions?

N/A

Might agents be erroneous in the prediction process, and how is it implemented?

Agents are wrong most of the time when projecting crop performance, crop markets, and weather. They estimate for the sake of a preliminary utility calculation, but just as in real farming, it is known that this is an estimate.

Interaction

Are interactions among agents assumed as direct or indirect?

Interactions are direct. Direct interactions take place through the built-in social network, with farmer and non-farmer agents communicating about their expertise and experiences with others close in their network. Indirect interactions have been proposed as a near-term improvement to the model. These would occur in the form of “looking over the fence” information acquisition wherein farmers learn information (somewhat flawed information) by watching those nearest them.

On what do the interactions depend?

Direct interactions depend on the social network. Indirect would depend on geographic location.

If the interactions involve communication, how are such communications represented?

Communications are represented as a simple positive or negative signal regarding a specific crop or irrigation practice. It is received and immediately applied to the recipient’s attitude about that crop or practice.

If a coordination network exists, how does it affect agent behavior? Is the structure of the network imposed or emergent?

No such network exists. Agents are assumed to act independently.

Collectives

Do the individuals form or belong to aggregations that affect, and are affected by, the individuals? Are these aggregations imposed by the modeler or do they emerge during the simulation?

No such aggregation exists in the district-scale simulation. In future, larger-scale simulations or in simulations that integrate multi-level decision making, agents would be aggregated into groundwater districts.

How are collectives represented?

N/A

Heterogeneity

Are the agents heterogenous? If yes, which state variables and/or processes differ between the agents?

Agents are dramatically heterogenous between breeds and more subtly heterogenous within breeds. Heterogeneity within breeds is primarily a factor of their possessions (farmers), experiences (farmers), and expertise (all).

Are the agents heterogenous in their decision-making? If yes, which decision models or decision objects differ between agents?

Breeds are heterogenous in their decision-making. Farmers are the only agents with deep and reactive decision-making. All other use simple scheduling mechanisms to share ideas.

Stochasticity

What processes (including initialization) are modeled by assuming they are random or partly random?

* Initial population of the world is semi-random around known means or otherwise informed by real-world distributions. This can be turned off and a saved world can be used to save time. When the world is populated randomly, agents are placed in a random location with a random amount of acreage pulled from a distribution of the users’ choice. The mean and spread of these distributions are based on real-world data.
* Regional precipitation is random, based on real-world averages and patterns.
* Maximum yield for each crop (before farmer action) is generated randomly each year, varying normally around a known mean.
* Initial characteristics of farmers are semi-random:
  + Equipment is randomly assigned to each farmer, based on known percentages of farmers who own each equipment type.
  + Starting money can be generated randomly for each farmer. By default, it is constant, because it is hypothesized that this initial value will have important impacts on farmer success rates.
  + Water right seniority and size are randomly generated. Water right seniority is normally distributed around the year 1930, accounting for the earliest right in approximately 1880 and representing the gradual end to ground water rights issuing in the 1980s. Other possible distributions for water right seniority are gamma and uniform, both of which have been programmed but are not in use. Water right size is assigned through either gamma or normal distribution.
  + Irrigation planning strategies are distributed randomly based on a known percentage of farmers who use each strategy.
  + The presence or absence of “other jobs” as a primary means of making money is distributed somewhat randomly among farmers. Farmers with small farms are more likely to have another job, but it is possible for any farmer to have one.
* Some land characteristics are generated randomly.
  + The history of a piece of land is generated semi-randomly based on the rotation of a farmer.
  + The type of irrigation installed on a piece of land is generated randomly based on known percentages of farmers who use each type.
  + Soil quality (referenced inversely as a construct called “input intensity”) at each patch is distributed randomly, although a setting can be changed on the interface to make this constant.
* A farmer’s annual irrigation plan is modified randomly to reflect their imperfect knowledge. The standard deviation of this modification is based on the accuracy of their monitoring strategy.
* The social network is randomly generated based on the classic Erdős-Rényi random network.

Observation

What data are collected from the ABM for testing, understanding, and analyzing it, and how and when are they collected?

Data are catalogued at the end of every season. At the end of the simulation, two main outputs are produced, a record of what crops were planted and a record of how many individuals adopted new irrigation practices (adaptation).

What key results, outputs, or characteristics of the model are emerging from the individuals? (Emergence)

The model does not seek to accurately predict individual behavior. Rather, it is targeted at accurately reproducing large-scale trends in cropscape and adaptation. Therefore, the primary products of interest are emergent phenomena.

Details

Implementation details

How has the model been implemented?

The model is primarily implemented in the open-source agent-based modeling platform NetLogo. It can be accessed through NetLogo directly or through the open-source statistical package R. R must be used to run extensive experimentation when the user wants to import previously generated worlds. Not enough precise control of variables exists in the NetLogo BehaviorSpace environment to work with imported worlds.

Is the model accessible, and if so, where?

The model, its components, and the associated data are all accessible in the public GitHub repository for the project.

Initialization

What is the initial state of the model world, i.e. at time t = 0 of a simulation run?

At time t = 0, all agents have been initialized, the groundwater district has been drawn and defined, and the social network has been established. Farmers have been generated with property, experiences, equipment, initial budget, and psychological characteristics. Other agents have been initialized with their attitudes about different crops and irrigation practices. All agents are mapped into the social network in the district.

Is initialization always the same, or is it allowed to vary among simulations?

Initialization can vary or can be held constant. Many of the parameters are semi-random, based on known distributions or population means in the district of interest. However, the random seed can be fixed to produce the same district twice, and the districts can be saved and imported for future use. This importing feature is the primary mechanism for experimentation, since random world generation is time-consuming.

Are the initial values chosen arbitrarily or based on data?

Nearly every value is based on data. A few exceptions exist, which are detailed in the codebook available in the GitHub.

Input data

Does the model use input data from external sources such as data files or other models to represent process that change over time?

No. The model uses input data from the AquaCrop crop modelling software, but this is not changed over time. Two such model couplings have been proposed, however. The first would couple the model with a hydrologic model of the Eastern Snake Plain Aquifer. The second would use a climate model to more accurately generate weather patterns over the course of the simulation.

Submodels?

What, in detail, are the submodels that represent the processes listed in “Process overview and scheduling”?

What are the model parameters, their dimensions, and reference values?

How were submodels designed or chosen, and how were they parameterized and then tested?

1. Hawes, J.K., 2019. Agricultural Adaptation to Water Scarcity. Purdue University. [↑](#footnote-ref-1)