Modelling Agent Personalities and Wealth Disparity in Predynastic Upper Egypt

PRNSAM002
Wilhelm Prins
Rondebosch 7700
University of Cape Town
Cape Town, South Africa
wilhelmprins@gmail.com
August 25, 2019

ABSTRACT

During the predynastic period of ancient Egypt, a process of increasing social complexity occurred, one of which the exact causes remain unknown to this day. Many explanations have been put forth trying to explain the reason for the sudden increase, but all have the explanations have been rejected, as they do not fit with the period nor the circumstances present in ancient Egypt. This lead to use of different methods of incurring on past events. A method that we incorporate is the use of archaeological computing, particularly agent-based modelling (ABM).

This paper presents the development of an ABM used to model the increase of social complexity of the period. The ABM investigates the effects that differing personalities have on wealth disparity and population distribution in the period, using these metrics as a measurement for social complexity.

1 INTRODUCTION

During the predynastic period of ancient Egypt (c. 4000-2900 BC), a society of small, relatively autonomous villages and households evolved into a large nation-state ruled by a single divine monarch. This drastic change in social complexity happened in a relatively short amount of time. While the exact cause that set of this process is still largely unknown and debated amongst the archaeological community, recent work on state formation in predynastic Egypt acknowledges that this process occurred as a result of overlapping complex social, economic and geographic factors [5].

For many years, scholars have tried to identify the cause of this rapid increase of social complexity, however all these scholars have had to face the many challenges involved with researching this time period [8]. These challenges include a highly fragmented archaeological record of the time period, which mostly consists of assumptions made from artefacts discovered left behind from the time period and the fact that the first signs of writing only appeared after Egypt was already a complex state [1, 2, 8]. However, with the information available, many of the traditional explanations of state formation (e.g. military threat, scarce resources, ideology, environmental determinants) that have been presented by anthropologists have been rejected by Egyptologists as these explanations are inapplicable to the circumstances of predynastic Egypt [3, 4, 12, 13].

Because of this lack of information and understanding, new methods of analysing Neolithic Egypt are required. One method that has gained more acceptance in the archaeological community is the use of computational archaeology [6] which involves the use of computational methods and modelling to infer archaeological events. A popular approach to computation archaeology is the use of agent-based modelling (ABM), which is a type of computational model that simulates the behaviour of autonomous agents in order to understand a complex system. What makes the use of computational archaeology and ABMs so attractive is the fact that they are extremely useful tools for when data is scarce and unknown, such as with the archaeological record of ancient Egypt, and they allow us to continuously simulate different what-if hypothesis about the events and factors leading to the process of state formation in ancient Egypt [9]. However, the use of such models do come with their own set of problems, while they are able to simplify complex variable interaction and create credible explanations of past events, it is worth noting that due to the principle of equifinality, the explanation offered by the ABM is only one of many plausible explanations as to the how the past unfolded [8, 9].

Even though ABMs have proven affective when studying various complex social phenomena in ancient civilizations, like evolving social networks [9], resource acquisition [7], etc., there are few examples of where ABMs are used to study the state formation process of ancient Egypt. Currently there are only two ABMs (discussed in 3.3) that study the social dynamics and effects that could have led to the increase of social complexity. The first models the spread of information and the gathering of the population in predynastic Egypt [10] and the second investigates wealth disparity and population distribution of predynastic Egypt when using agents with differing personalities [5].

This paper reports on an ABM developed by adapting and extending the ABM described by Nitschke et al [5] and enhancing it with elements from the model described by Symons and Raine [10], particularly the movement of households to form villages and the total spread of knowledge between households. The use of personalities have been proven to be useful in creating more sophisticated simulations of human behaviour and encourages emergent behaviour from the agents [11]. The new ABM will involve the differing personalities of the agents in the decision making process for household movement, with the purpose of simulating more human-like decision making [6] and increasing a households quality of life. An essential ingredient to creating more credible explanations to the increase in social complexity is the observation that humans everywhere prefer to live better lives [15], thus we allow agent to relocate if it can improve its quality of life. Combining the use of differing personalities and agent movement led to the following research question:

1.1 Research Question

The aim of this paper is to investigate the effects on wealth inequality and population distribution in ancient Egypt, when an agent's decision to move to another village or stay at its current village is governed by specific personality traits, namely competence, ambition and loyalty.

2 BACKGROUND

2.1 Ancient Egypt

During the predynastic period (c. 4000-2900 BC), a process of increasing social complexity led to the evolution of small, relatively autonomous villages and households into the formation of a large nation-state ruled by a divine monarch, all in a relatively short amount of time. This process seemed to occur in Upper Egypt first, near the Qena bend, where the archaeological evidence suggests the emergence of three major settlement, with each having their own associated territories and cultures and are characterized by a growing social hierarchy and wealth inequality. Eventually one of the three major settlements grew larger than the rest, expanding its culture and control over first the rest of Upper Egypt, and then expanding northwards over the rest of the Nile Valley resulting in a unified state that lasted for several thousand years [1, 2, 8].

The exact causes behind this rapid increase in social complexity is still poorly understood [8]. This lack of understanding is partly due to the highly fragmented archaeological record of the Neolithic time period, consisting mostly of assumptions made from the artefacts discovered from the time period, and a lack of written records, as writing was only established when Egypt was already a complex state [1, 2, 8].

2.2 Agent-Based Modelling (ABM)

Agent-based modelling is type of computational model that simulates the behaviour of autonomous agents in order to understand a complex system. In a historical setting these agents can be used to represent anything from individuals to households or even large population groups.

The agents are placed within an artificially constructed environment, which represents the real world to some degree, with rules controlling how agents interact with the environment and other agents. As the agents interact with their environment and each other various social phenomena can be observed to emerge.

ABMs are particularly well suited to minimize the effect of equifinality, this principle states that the past could have unfolded in multiple ways, each which could have resulted in the same evidence we are presented with today, because by using an ABM we are able to simulate many hypotheses about the past simultaneously, matching the results against the evidence we see. This can improve our ability to home in on more credible historical narratives [8, 9].

2.3 Related ABMs

There are currently two published models that study the process of state formation in early Egypt. One by Symons and Raine [10] and another by Nitschke et al [5]. In both these models, the agents have to decide where to farm and live along the Nile flood bank where the models simulate a yearly flooding that effects a farms fertility.

The model by Symons and Raine models the spread of information and the gathering of the population in predynastic Egypt. In this model agents are represented by households living in villages who collectively decides where to farm. Information about field fertility and village wealth is exchanged between agents when they farm fields that are adjacent to each other. If the model is run in total information mode, agents have access to information about all other villages and not just adjacent ones. After each year, the harvest for a village is calculated and distributed among the household that make up the village. After a household has received their part of the harvest, the household can compare its harvest versus the knowledge it has of other villages and may decide to move to another village if it is seen as an improvement on its current lifestyle. Their model displayed patterns of population settlement along with the overall average grain possessed by household under various model parameters.

The model by Nitschke et al was developed using elements from the Symons and Raine model as well as use the conceptual model put forth by Kemp [1]. Kemps conceptual model likens the process of state formation to a game of monopoly where all "players" initially start as equals in a landscape of unlimited potential. The players would compete over resources with the advantage swinging from one player to another and eventually this advantage position will reinforce itself on one or more players, symbolising an entrenched inequality.

The model by Nitschke et al specifically looks at settlement agglomeration and the development of wealth inequality based on environmental fluctuations and differing personalities of the agents. The model demonstrated that even small fluctuations of the Nile flood combined with the decisions made by the agents, all with differing personalities, can lead to massive wealth inequalities and large settlement sizes.

The ABM described in this paper is developed using the ABM by Nitschke et al as the foundation and using elements from Symons and Raine to extending the functionality of the ABM in order to investigate the effect of differing personality traits on wealth inequality and population distribution when agents have to decide whether to move to another village or stay at their current village.

3 Methods

3.1 Translation to Python

The ABM developed in this paper was created by translating the ABM by Nitschke et al from an implementation in NetLogo to one in python. The main reason for this translation is because python has access to many useful packages related to ABMs and evolutionary computing which can be used to create more complex models easier than when using NetLogo.

3.2 The Agent-Based Model

The ABM by Nitschke et al [5] simulates ancient Upper Egypt in an abstracted version of the Nile floodplain with baseline values for population density taken from Butzer (1976) [14], while average values for settlement density, agricultural production and grain consumption are taken from Hassan's geoarchaeological studies on the Egyptian Predynastic landscape [12]. These values are used to control the agricultural and demographic behaviour of the model [5].

In the model, the agents represent households. At the start of the simulation, a number of settlements are created, the number of settlements are defined by the user. These settlements are comprised of a number of household, also specified by the user, and placed randomly on the abstracted floodplain. Each agent begins with an equal amount of workers and an equal amount of resources. Each tick of the simulation represents a year. During each tick, households have to decide if/where to claim available land and if/where to harvest. These decisions are based on the following agent variables: field-knowledge, distance of the fields from the household, ambition, competence, current grain-storage, and the number of workers.

Ambition and competence are used to encourage emergent agent behaviour and more closely mimic human decision making [11]. Values for competence and ambition are randomly assigned to each household at the beginning of a run, having a minimum value as set by the user before model setup. These values are updated at a random interval (10 – 15 year) for each household. This to reflect a change in leadership of the household. This change is governed by the generational-variance factor with is set by the user before model setup.

The harvest yield of a field is determined by the average-yield-per-field value (set by the user before model setup), the field's fertility, the competence level of the household and the distance from the household to the field. The fertility of fields changes every year by using a flood function, adapted from the model by Symons and Raine, which simulates the annual Nile flood variability. This function then determines a new fertility value for a filed based on the distance from the Nile.

After households have harvested their selected fields, they consume grain based on the amount of workers it has and then set aside grain to be used to seed the fields, any surplus grain is stored. If a household does not have enough grain at the end of a year, it must lose a member. When all members of the household has been lost, that household gets removed from the simulation. If the household has a surplus of grain at the end of a year, it has the opportunity to gain a member, this is determined by a households ambition and competence values and the amount of grain the household has. In order to keep the model in line with the current consensus about actual population numbers and growth rates in Predynastic Egypt, the total number of household members are restricted by the pop-growth-rate (set by the user before model setup).

3.3 The Extended ABM

The section will cover the alteration made to the model described above.

Settlements

Settlement consist of one or more households. In the initial model, the simulation enabled a user to set the amount of settlements and the amount of household that make up the settlement. This has been changed so that each settlement only have one household at the start of the run. This household is the settlements leader.

Households

Households were unable to relocate to another settlement. In the extended model, a household is able to decide if it wants to move to another settlement or stay at its current settlement. This option is made available when the household's average ration per worker (Equation 3.3.1) is less than 2.5, meaning the household has enough grain to feed its workers for another 2.5 years. This value is updated at the end of each year after a household has consumed their grain.

$$\frac{\frac{Total\ grain}{Worker\ ration}}{Number\ of\ workers} \quad \text{Equation 3.3.1}$$

When a household is able to move, the decision to do so is controlled by the household's competency, ambition and loyalty. Loyalty represents the household's loyalty to its head household, the settlement leader, or as an attachment to its land if it is the settlement leader. The Loyalty value changes every year based on the amount of grain a household received that year.

The process for deciding to move is as follows (Appendix A Figure 1):

1. The household's loyalty is tested. If a random generated number is smaller than the loyalty value of the household, the household will decide not to move. This means that the higher the loyalty value, the more it will choose to stay at its current village.
2. A Bayesian network is used to determine if the village will move or not. This network uses the values for competency and ambition of the household. Firstly the ambition of the household is tested. If the household has an ambition larger than 0.6 it is considered ambitious.
3. Next the competency is tested. If the household has a competency larger than 0.6 it is considered competent.
4. We now know if the household is competent and/or ambitious. Figure 3.3.2 represents the probability of the household moving based on the values from steps 2 and 3.

   Example: If a household is ambitious but is not competent. The household will then have a 30% chance to move and a 70% chance to not move.

Is Ambitious	Is Competent	Move	Do Not Move
1	1	0.05	0.95
1	0	0.3	0.7
0	1	0.5	0.5
0	0	0.9	0.1

Figure 3.3.2 1 meaning true and 0 meaning false. Table contains the probabilities of an agent's action based on the competency and ambition result from step 3 and 4. Ambitious agents will try to farm their own fields for longer than unambitious agents do. Competency directly influences the amount of grain a household receives from a harvest, thus being competent increases the probability of not moving.

5. If a household decides to move, it will only move to another household if it can improve its quality of life by at least 20%, measured by comparing its grain to the amount of grain of another settlement. If such a settlement is available, the household will relocate to the settlement with the best improvement to its quality of life and spend 15% of its current grain as a cost to moving. If no such village is available, the household will remain at its current village. Values for quality of life and movement costs adapted from Symons and Raine [10].

Harvesting fields
When a settlement harvests their fields, the grain harvested by all the household in that settlement is added together and then distributed evenly amongst the households, with exception to the village leader which receives 20% of the total harvest plus its share of the harvest.

3.4 ABM Setup Parameters

The initial setup parameters (Appendix A Figure 3) for a run includes:

- Starting-household – determines how many households will be within a settlement.
- Starting-settlement – determines the initial amount of settlements.
- Starting workers – specifies the amount of workers each household has.
- Average-yield-per-patch – an average value for grain that a household will receive when harvesting a filed. This value is multiplied with the field's fertility value and household's competence value to determine harvest of the field.
- Min-Ambition – specifies the lowest initial value for household ambition, which influences whether a households gains a member and whether to claim/harvest fields.
- Min-competence Competency – specifies the lowest initial value for household competency, which directly influences the amount of grain a household receives from harvesting a field.
- Generational-variation – used to change a household's ambition and competency as leadership changes within the household.
- Knowledge-radius – a household has knowledge of fields within this range.
- Grain-cost-per-unit – cost of walking to a field to claim/harvest.
- Fallow-limit – specifies the amount of year a field can lay fallow before another household may claim it.
- Pop-growth-rate – used to restrict population growth.
- Worker-ration – the amount of grain each worker needs to consume at the end of year.
- Worker-outsource-cut - households are allowed to farm other households' unharvested fields. The owner of the farm takes a cut of the profits determined by the worker-outsource-cut.
- Min-loyalty - specifies the lowest initial value for household loyalty and is used to determine whether a household is loyal to its land or head household.

4 RESULTS AND DISCUSSION

All experiments were run for a timeframe of 500 years using the same setup values except for the values of min-ambition and min-competency. These variables were alternated between low, medium and high values (Figure 4.1). Each experiment is comprised of 15 settlements containing one household each. The settlements are placed at random locations with an appropriate distance between each settlement. Each household starts with an equal amount of resources (7500 grain) and an equal number of workers (10). This allows for a generous starting average ration per worker (Equation 3.3.1) and discourages immediate household movement. Values for Average-yield-per-patch, Generational-variation, knowledge-radius, Grain-cost-per-unit, fallow-limit, pop-growth-rate, worker-ration and worker-outsource-cut are taken from the original model by Nitschke et al [5]. Average-yield-per-patch is set to be in line with what is expected from the period (2775). The knowledge radius is set high in order for all agents to have equal knowledge of the fields and generational changeover is set high in order to simulate greater personality change when a household's leader is replaced. All households will start with a randomly allocated loyalty value higher than the Min-Loyalty value. The Min-Loyalty value will remain constant throughout all experiments (0.4).

Experiment	Minimum Competency	Minimum Ambition
1	0.1	0.1
2	0.1	0.5
3	0.1	0.9
4	0.5	0.1
5	0.5	0.5
6	0.5	0.9
7	0.9	0.1
8	0.9	0.5
9	0.9	0.9

Figure 4.1 Initial Min ambition and Min competency values for run of each experiment.

Each experiment evaluated the wealth distribution of households and settlements, the distribution of the population and any interesting behavior that emerges. Primarily, we are concerned with whether or not an inequality emerges. Inequality is determined using the gini-index [16] (Appendix A Figure 2) and population wealth.

In the first three experiments, when minimum competency was set low, inequality was high early on in the runs. Households tended to abandon their own land and move to a more successful village early on, but because of the low competency values combined with the varying ambition values, harvest yields was not enough to sustain villages for long. In most runs the population saw a drastic decline until a balance was found. This happened mostly in the runs with medium and high ambition values. The low harvests is due to the fact that a household's decision to claim fields and whether or not to harvest them is influenced by their ambition and competency level. The lack of resources to sustain the household then lowers its loyalty towards its land or head household, making the decision to move much more likely. When a balance in the population was found, nearing the end of the run, there tended to be between 1-3 settlements remaining, each containing some amount of the remaining households. This number would continue to decrease until no household was left when ambition and competency was set to low values.

When the minimum competency was set to a medium value, households were able to produce more grain, which in turn lead to the average loyalty to be higher. This means that household were moving less frequent than they did when competency was low, but moving was still occurring. At the end of each run, 2-3 settlements were established, these settlements resembles the process of forming proto states from small egalitarian communities [1]. After the settlements had formed, moving became less frequent because of better harvest yields, which in turn increased a household's loyalty towards its current position. The overall population of the flood plain increased over the years, with only some minor deterioration in some years, larger when ambition was low. A larger equality in household wealth was observed as the minimum ambition value was increased. Household tended to have about the same amount of grain, with the exception of the head households. This is to be expected, because settlements divide their harvests equally amongst its households. Even though the wealth of each household seemed similar, using the gini-index, we observed that there was indeed an inequity to them (Appendix A Figure 4.3, 4.4, 4.5).

When competency is high and ambition is low, the results are very similar to above, except that households are moving less frequently and more settlements are present at the end of a run. Household movement becomes considerably less frequent as the minimum ambition increases. Household have similar amounts of wealth until one household decides to move and form a settlement with another household. The households that form part of a settlement tended to generate more grain than those that decided to remain independent. This led to slow and steady increase in inequity (Appendix A Figure 4.6) for all combinations of competency and ambition values. The population growth for the high competency runs remained positive throughout all runs, with only minor deteriorations to the population on some years early on in the runs.

5 CONCLUSIONS

Inequality was greatest when households had more different personalities, indicating that differing personalities could have played a part in the process of increasing social complexity. Nevertheless, indications of inequality was also observed even when household personalities are close to each other, this inequality would become greater as time passes. The results show that when differing personalities are used to determine whether a household should move can lead to an entrenched inequality. The ABM was also able to represent some artifacts from the known archaeological record to some degree, like the emergence of proto states and the competition between those proto states for resources and members.

6 FUTURE WORK

As is, the model is too simplistic and should be improved. Future work will include; introducing additional personality traits that will effect a households decision to move; altruism values for each household which will determine how much of the harvest the household will take if it is the head household of a settlement; the ability to break free from a settlement to start a new settlement; and the ability for households to decide that staying loyal to their own land is less beneficial than joining a settlement, even if the household is producing a surplus every year.

REFERENCES

[1] Barry J. Kemp. 2014. *Ancient Egypt Anatomy of a Civilisation*, Florence: Taylor and Francis.

[2] Douglas J. Brewer and Emily Teeter. 2010. *Egypt and the Egyptians*, Cambridge, UK: Cambridge University Press

[3] Carneiro, R.L. 1987. Cross-currents in the theory of state formation. American Ethnologist. 14(4):756–770.

[4] Flannery, K.V. 1999. Process and Agency in Early State Formation. Cambridge Archaeological Journal. 9(1):3–21

[5] Geoff Nitschke, Jessica Nitschke, Alexander Furman, and Matthew Cherry. 2017. Modeling patterns of wealth disparity in predynastic Upper Egypt. *Proceedings of the 14th European Conference on Artificial Life ECAL 2017*(2017). DOI:http://dx.doi.org/10.7551/ecal_a_054

[6] Mark W. Lake. 2014. Explaining the Past with ABM: On Modelling Philosophy. *Advances in Geographic Information Science Agent-based Modeling and Simulation in Archaeology*(2014), 3–35. DOI:http://dx.doi.org/10.1007/978-3-319-00008-4_1

[7] Marzieh Jahanbazi, Christopher Frantz, Maryam Purvis, Martin Purvis, and Mariusz Nowostawski. 2014. Agent-Based Modelling of Primitive Human Communities. *2014 IEEE/WIC/ACM International Joint Conferences on Web Intelligence (WI) and Intelligent Agent Technologies (IAT)*(2014). DOI:http://dx.doi.org/10.1109/wi-iat.2014.151

[8] Robert J. Wenke. 2009. *The ancient Egyptian state: the origins of Egyptian culture (c. 8000-2000 BC)*, Cambridge: Cambridge University Press.

[9] Shawn Graham and Scott Weingart. 2014. The Equifinality of Archaeological Networks: an Agent-Based Exploratory Lab Approach. *Journal of Archaeological Method and Theory*22, 1 (2014), 248–274. DOI:http://dx.doi.org/10.1007/s10816-014-9230-y

[10] Symons, S. and Raine, D. (2008). Agent-based Models of Ancient Egypt. In Proceedings of the Meeting of the Computer Work- ing Group of the International Association of Egyptologists, pages 129–146. Gorgias Press.

[11] Tomas Trescak, Anton Bogdanovych, and Simeon Simoff. 2016. Personalities, Physiology, Institutions and Genetics:

Simulating Ancient Societies with Intelligent Virtual Agents. *Computational Social Sciences Simulating Prehistoric and Ancient Worlds*(2016), 377–404. DOI:http://dx.doi.org/10.1007/978-3-319-31481-5_14

[12] Hassan, F.A. 1997. The Dynamics of a Riverine Civilization: A Geoarchaeological Perspective on the Nile Valley, Egypt. World Archaeology. 29(1):51–74.

[13] Savage, S.H. 2001. Some recent trends in the archaeology of predynastic Egypt. Journal of Archaeological Research. 9(2):101–155.

[14] Butzer, K. (1976). Early Hydraulic Civilization in Egypt: A Study in Cultural Ecology. University of Chicago Press.

[15] Claudio Cioffi-Revilla. 2018. *Introduction to Computational Social Science Principles and Applications*, Cham: Springer International Publishing.

[16] Frank A. Farris. "The Gini Index and Measures of Inequality." *The American Mathematical Monthly* 117, no. 10 (2010): 851-64. doi:10.4169/000298910x523344.

Appendix A

```python
def move(self, ambition, competence, loyalty):
    a = 0
    c = 0
    m = 0
    l = 0

    num = random.uniform(0, 1)
    if num < loyalty:
        return False

    if ambition >= 0.6:
        a = 1
    if competence >= 0.6:
        c = 1

    num = random.uniform(0, 1)

    if a == 1 and c == 1:
        if num <= 0.05:
            m = 1
    elif a == 1 and c == 0:
        if num <= 0.3:
            m = 1
    elif a == 0 and c == 1:
        if num <= 0.5:
            m = 1
    elif a == 0 and c == 0:
        if num <= 0.9:
            m = 1

    if m == 1:
        return True
    else:
        return False
```

Figure 1 Python code for the agent move decision making process.

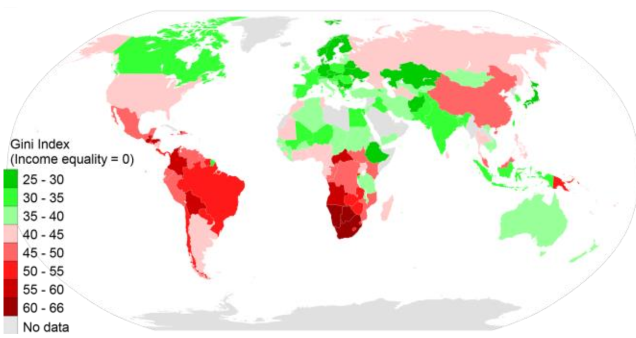

Figure 2 Gini-Index (**Source:** Combined data from: World Bank GINI index (2014); The World Factbook, CIA (2011); Human Development Report, UNDP (2009))

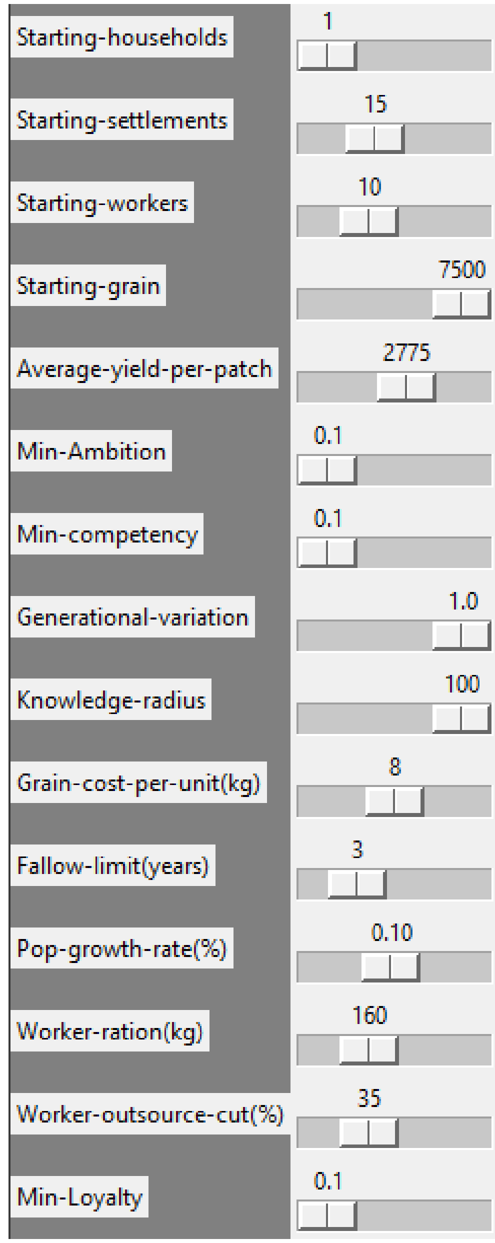

Figure 3 Parameter sliders for initial setup values

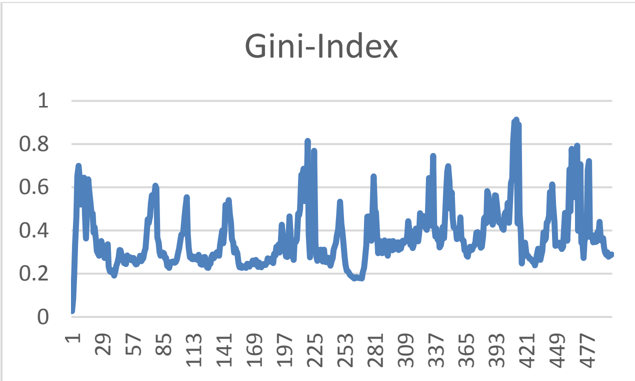

Figure 4.3 Example run of experiment 6

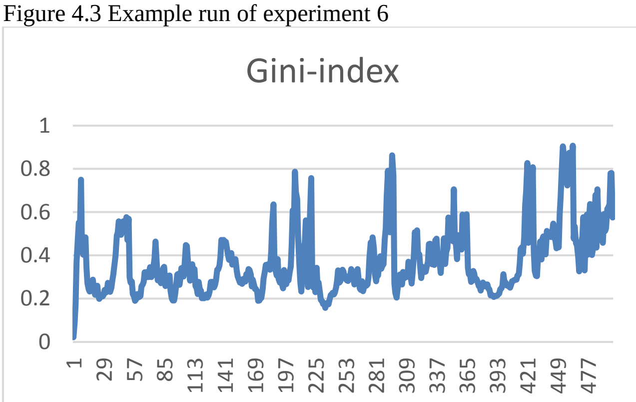

Figure 4.4 Example run of experiment 5

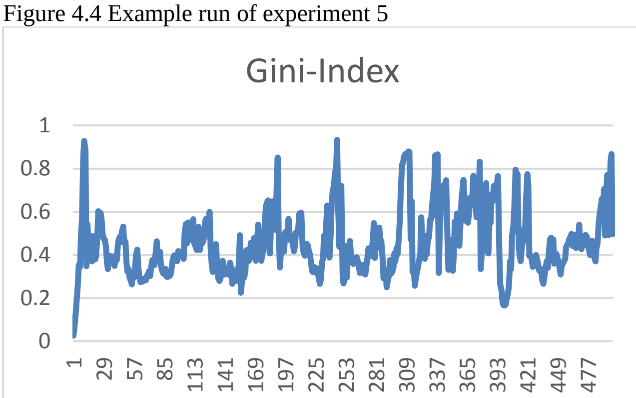

Figure 4.5 Example run of experiment 4

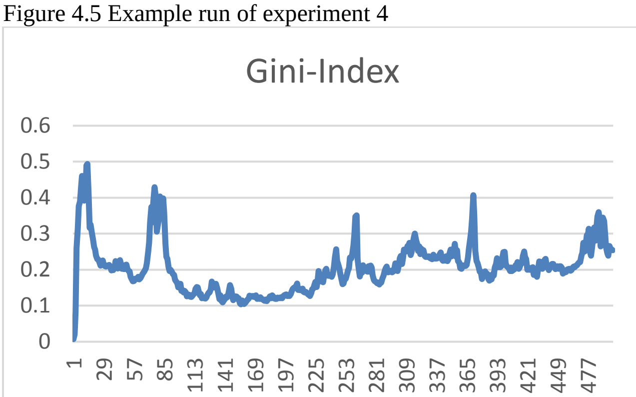

Figure 4.6 Example run of experiment 8