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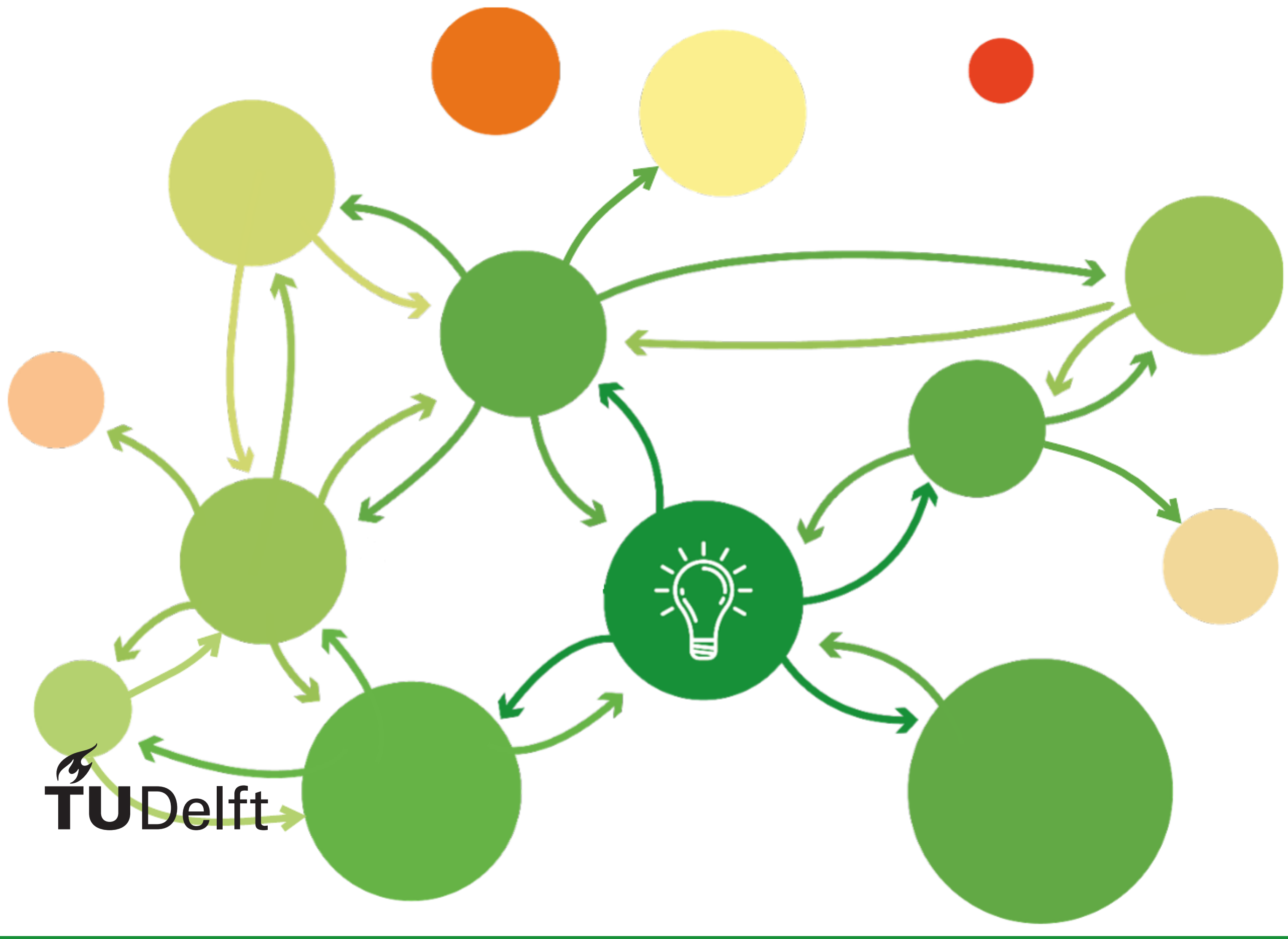
A study on how leadership emerges through an innovation process for solving community problems

Mohammadhosein Hamedtavasoli



TU Delft

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A study on how leadership emerges through an innovation process for solving community problems

by

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An electronic version of this thesis is available at http://repository.tudelft.nl/.
The final version of the model and the analysis code are available at
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Summary

Many regions around the world are facing water shortage, low water quality, unsustainable overuse or other problems that may even cause conflict among different actors. These water resources are typical examples of common-pool resources. Despite being labeled as the tragedy of commons, there are many examples of community-based management of water resources that are successful and sustainable. Leaders seem to play a crucial role in the emergence of community-based management of resources and overcoming the collective action problem. This is why I chose leadership as the focus of this study.

Cultural background and institutions of each community affect the role of leader and the mechanism through which the collective action in communities start. I chose to focus on communities in which, collective choice institutions require general agreement to change operational institution and there is no authoritative rule based on operational institutions because this seems to be the case in many small communities where people started successful collective action. In such communities, leaders themselves emerge in the process of initiating collective action. Based on this choice, if the focal institutions are similar, the findings of this study can be applied in different domains of collective action. The main purpose of this study is to find the mechanism behind the emergence of leaders in the process of starting collective action.

For this purpose, first, I performed an extensive literature review. Due to lack of an adequate theory that can explain the role of leaders in the initiation of collective action in communities, I synthesized leadership studies from different domains and created Leadership for Community Development (LCD) theory. I further improved this theory with the insights that I gained from the modeling steps.

In this theory, I explain leadership emerges from influencing interactions that are done to share a vision and make other community members dedicated to it. In this process, leaders gather the requirements of collective action, like support or political capital. Central to this idea is the innovation process, which has four phases of idea generation, idea elaboration, idea promotion, and idea adoption. The idea in the innovation process is the same as the vision.

According to this theory, first, there might be problematizing leaders who challenge the current state and give attention to a problem through influencing interactions. Dissatisfaction with the current state can lead to idea generation. This is the start and the first phase of the innovation process. In the idea elaboration phase, the idea creator will try to elaborate and gather support for the idea among his or her close connections. If this is successful and enough support is received, dedicated actors will start promoting the idea by influencing others. In the idea promotion phase, enabling leadership emerges when actors promote their own vision and echoing leadership emerges when convinced actors advocate the vision of their influencers. In other words, enabling leadership comes from an internal motivation while echoing leadership comes from an external drive and seems like reflection. Enabling leadership and echoing leadership form up effective leadership, which is the indispensable influencing effort of actors for reaching the next phase. Idea adoption or implementation only starts when requirements such as political and intellectual capitals are enough. This phase is in the domain of management and is not part of the focus of this study.

To support this theory, I studied a case and interviewed a local water management expert. The case is in Mojen, Iran. In this town, a new management system emerged over 50 years ago and it has been successfully in place since. This case is also a source of inspiration and ideas for this study. By this interview, I deduced idea elaboration, idea promotion and idea adoption has happened in the process of change in Mojen. These findings supported the LCD theory.

Based on my findings through theory development and the case study, I structured factors of a social-ecological system which are relevant to the role of leaders in the initiation of collective action using the Social-Ecological Systems (SES) framework (Ostrom, 2009b). This helped me to choose factors and institutions that are needed to be included in the model conceptualization. I suggested some changes such as separating the social network from the social capital and distinguishing the difference between leaders and managers for the proper adaptation of this framework to the LCD theory.

Based on the LCD theory, the chosen factors and institutions, and inspirations from the case I created an agent-based model. The model was a successful proof of concept for the LCD theory and how the identified types of leadership emerge through the process of initiating collective action. The model produced emergent outcomes that were realistic and consistent with the theory. This model, to best of my knowledge, is a first attempt in modeling the emergence of leadership through influencing interactions.

I used the model to identify the most significant factors on the role of leaders and the initiation of collective action. The social network proved to be the most important factor. I designed two sets of final experiment. The first one was understanding the impact of different network metrics that I found to be most relevant. In the second one, I tried to understand the impact of inequality in farm size of actors and the change in the system behavior if actors' prestige depends on their endowment.

Based on these experiments I found a higher average number of connections per actor has a desirable effect and decreases the ecological pressure that is necessary to trigger successful idea adoption. The emergence of echoing leadership also becomes more prominent. Increasing the population, on the other hand, has the opposite impact. Inequality in farms or endowments can decrease the ecological pressure that is needed to make a system adopt an idea and emergence of enabling and echoing leaderships becomes more prominent. Moreover, if the prestige of community members depends on their endowment more ecological pressure is needed for the adoption of a new idea and the emergence of the aforementioned leadership types become less significant.

Based on these findings, I suggested to those, who intend to help in solving community problems, to focus on networks and building connections in the communities. Moreover, I have suggested using these findings to diagnose the lack of collective action in communities in response to problems and to use this diagnosis in the process of facilitating collective action in communities.

I proposed many recommendations for future steps in this study. The top priority recommendations are a call for case studies to be done to further validate the LCD theory and to perform group experiments to increase understanding of the role of the social network in collective action problems.

Contents

1
Introduction

Water resources have an undeniably crucial role in every society and human life everywhere. From ancient times until nowadays, adequate access to water has been a root cause of many conflicts (Gleick & Heberger, 2011). The Syrian civil war is a contemporary example of these conflicts (Gleick, 2014). Many regions face water scarcity problems (Hoekstra, Mekonnen, Chapagain, Mathews, & Richter, 2012), while the increase in the world population will give rise to water demand (Vörösmarty, Green, Salisbury, & Lammers, 2000) and climate change might make water more scarce in many areas (Arnell, 1999). It is estimated that by 2050 more than half of the world's population may face freshwater shortage (Rockström et al., 2009). All these show the urgency of the need for better management of water resources. These mentioned studies point out the societal relevance of this proposed study.

Most of the water resources can be classified as common-pool resources, as it is hard to exclude people from using the resource and there is a rivalry in use, i.e. the water consumed by one user is not available to others. Early studies of CPRs concluded that their only possible outcome is a competitive non-cooperative situation which will lead to depletion of resources (Hardin, 1968; Madani & Dinar, 2012a). Hardin (1968) described the outcome of a common-pool resource (CPR) with the famous expression of "tragedy of commons". Based on his study users of a CPR will overuse their shared resource until the point of destroying it. He argued there are no technical solutions and there is a need for restrictions through privatization or government ownership of common resources.

After the 1980s, with increased concerns about resource overuse and failure of market mechanisms and state regulations, attention to the common property has increased. Even governments and policymakers have started to support decentralized governance of common resources by the communities (Agrawal, 2003). Around the same time, Elinor Ostrom and her colleagues found that there are numerous examples of self-governed CPR that do not have the fate of overuse and depletion of the resources (Ostrom, 2010). This self-organization is an alternative to popular institutional arrangements of markets or regulations by the government (Ostrom, 2010). These studies show most of the instances where sustainable use of a CPR is achieved, it was due to institutions that emerged from inside communities which were using the resources. This means self-governance of CPRs is desirable. Comparing to the early perception of impossible success of CPR management, Madani and Dinar have shown that even non-cooperative institutional setting can lead to a better outcome than the overuse described by Hardin's "tragedy of commons" (Madani & Dinar, 2012b).

Although the knowledge of CPRs and the self-organization institutions has increased, still it is not known perfectly how to initiate successful community-based governance. Strictly regulating CPRs while peoples' life depends on it can be immoral and cause social unrest, and nonetheless, it has not proven to be successful in many cases.

To understand factors that contribute to the effectiveness and success of these self-organizations, Ostrom and colleagues developed the Social-Ecological System (SES) framework (Ostrom, 2009b). The result is an extensive list of factors which relates to features of the ecological system, resource unit, community, and government structure at place. As some examples of these factors, leadership, the size of the ecological system, and the population of users can be mentioned.

The high number of factors which are identified in the literature creates difficulties for a complete analysis. Indeed, Agrawal, by analyzing and comparing different far-reaching works on sustainable self-organized CPRs (including those of Ostrom), argues that providing a list of requirements for such successful governance is impossible and instead of a single case study, researchers should shift their focus to comparative analysis (Agrawal, 2001, 2003). One of his arguments is based on the existence of extensive internal and external (which is usually neglected) factors which may cause the wrong assumption when a researcher is trying to come up with causal relations between these factors (Agrawal, 2001). This means any research done on CPRs needs to be a cautious comparative study and the researchers need to carefully identify factors and their relations.

Based on the lessons which can be learned from these studies, I will focus on a specific element which contributes to sustainable governance of CPRs. To have a better picture of the emergence of self-governance of CPRs, I will analyze studies related to the collective action theory, because, cooperation in a community for sustainable use of a CPR can be seen as a collective action problem (Ostrom, 2009a). Usually, leaders have a prominent role in collective action problems and as communities become bigger and more complex, the leadership role becomes more institutionalized (Glowacki & von Rueden, 2015). In one extensive analysis of fishery case studies – which is a typical common resource – leadership was the most important factor in the success of collective actions (Gutiérrez, Hilborn, & Defeo, 2011). Nevertheless, leadership has not received the needed attention in the common source literature and it is an area which is lagging behind (Lobo, Vélez, & Puerto, 2016).

Heterogeneity of power is undeniably very influential on the result of any collective action (Bardhan & Ray, 2008 cited in Lobo et al., 2016). Heterogeneity of users should be differentiated from inequality and heterogeneity itself can be seen from different perspectives (Komakech, van der Zaag, & van Koppen, 2012). Komakech et al. (2012) mention several aspects of heterogeneity, namely political heterogeneity or decision making right which relates to leadership and economic heterogeneity which may prompt richer users to contribute more to the start of collective action. They further argue the interdependence caused by such heterogeneity may contribute to the start and survival of collective action.

The leadership can manifest itself as a group of people instead of a single leader, in which case the power relationships among this group will be of great importance (Vedeld, 2000). Leadership can be studied from different points of views like how they influence the community or how they are chosen to be leaders (Sahin, Eckel, & Komai, 2015). Leaders can play their role by different tools in different types of actions. Glowacki and von Rueden (2015) mention the importance of leaders in coordination, monitoring, solving conflicts and sanctioning in particular. Leaders might set an example for others to follow or motivate others by talking to them (Sahin et al., 2015). Lobo et al. (2016) consider two dimensions of internal organization and outside communication for the role of leaders. Leadership can be seen as a factor that exists in the system (like heterogeneity in decision-making rights) or as an emergent behavior of the system alongside the emergence of collective action. As will be discussed in more detail in chapter 2, the latter is chosen, because in many cases where communities are starting to act collectively, decision making is inclusive and there is no difference in decision-making rights (Harley, Metcalf, & Irwin, 2014; Martiskainen, 2017; Onyx & Leonard, 2011).

Based on the mentioned literature, I see a knowledge gap about how leaders emerge in a community to push for change and how they contribute to solving collective action problems by interacting with their society, external actors and environment. This is the scientific relevance of this study. Assuming that self-organization of CPRs can greatly help the sustainable use of these resources, and also assuming the importance of leaders for starting a collective action, this research aims to take a step towards a better understanding of how leaders contribute to starting a collective action for community-based governance of water commons. This knowledge can help in finding means of supporting initiation of community-based governance.

It is important to emphasize that in this study my focus is on the initiation of collective action. Success or failure of a new governance system is an issue of management. This differentiation will become clearer in the following chapter. Hence, the main research question of this study is:

> What mechanism can explain the emergence of leaders in the process of initiating community-based governance of common-pool water resources?

Multiple policy streams model of Kingdon and Thurber (1984) works very fine in pointing out the main concepts and the aim of this study. In this model, there are three streams of policy, problem, and politics. In the context of common pool water resources, the problem stream can relate to water shortage, and the policy or solution stream may be a new institutional setting. The politics stream refers to the willingness and the possibility of implementing a policy to a problem for decision-makers. To adopt a policy, these streams must coincide, which is called a policy window. Actors will try to find solutions and support for their problems. According to this model, actors can have a policy and try to find a problem and support for it (Enserink et al., 2010). The aim of this study is find how leaders emerge and the role they play toward making these streams meet.

In what follows the research approach is presented. It includes finding on the nature of CPRs and as well as recent developments in modeling CPRs using agent-based modeling. The research approach is built on synthesizing relevant theories to create a new leadership theory regarding communities and modeling the main concepts of the theory. These are done inspired by a case that is the subject of the interview done for this study. Sub-questions are presented at the end of this section. The research method and the structure of the study follow next.

1.1. Research approach

First attention should be given to the nature of the system in governance and management of CPRs. Water resources and communities together create a social-ecological system, both affecting each other. Communities can be seen as complex adaptive systems, in which behavior of the system is the result of actions and interaction of many actors that can be individuals or sub-systems (Waldrop, 1993) and these actions and interactions are influenced by institutions in place (Giddens, 1984; Scharpf, 1997, p.12 cited in Ghorbani, Bots, Dignum, & Dijkema, 2013). Institutions are sets of accepted rules that structure individual behavior and interactions (Hodgson, 2006). Institutions exist on different levels of operational, collective choice, constitutional, etc. (Ostrom, 2009c). A change in the lower-level institution will happen based on higher-level institutions. Institutions that are used for governing user behaviors in common resources are themselves operational, therefore to modify or create institutions at this level, institutions at collective choice level become relevant and should be considered as given.

In this study, I use operational and collective choice institutions to describe the interactions of actors with each other or with the ecological system. Although collective action under study might lead to a new operational institution, I am interested in observing the emergence of leadership in the early stages of collective action, and since this process itself is governed by collective choice rules, this level of institutions are more relevant.

Since the literature on collective action plays an important role in this study it is important to elaborate on this connection. Typical solutions to a CPR problem can be regulation (which may be imposed by higher-level organizations), new or improved infrastructures, community-based management or a combination of these solutions. All community-based management solutions, which require cooperation among users, can be considered collective action. Some infrastructural solutions may also need cooperation to gather necessary capital or manpower for implementation, and therefore, they are considered collective action as well. Collective action in communities, which are social interaction fields (Wilkinson, 1991, p.12 cited in Pigg, 1999), includes many other problem (or opportunity) domains as well. As an interesting contemporary example, I can mention the grassroots innovation projects. Figure 1.1 is a representation of this idea using a Venn diagram.

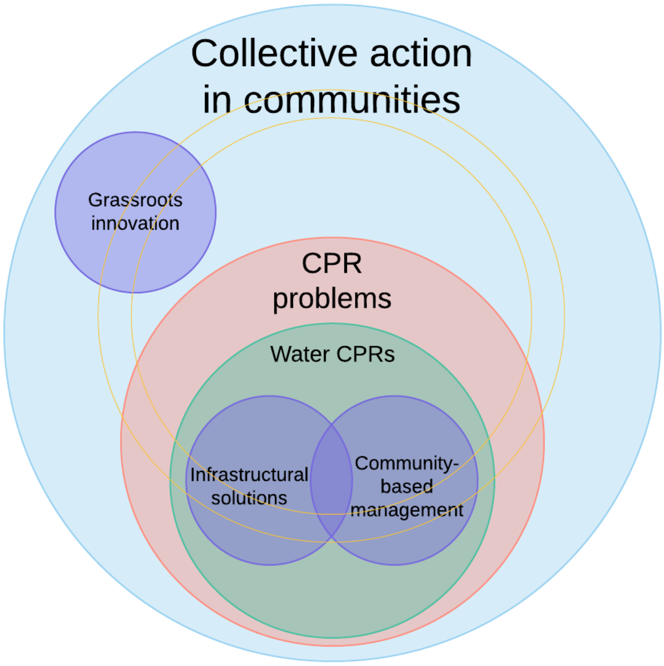


Figure 1.1: Venn diagram used to describe the relationship between collective action in communities and solutions to common pool water resource problems. Size of circles are chosen arbitrary and without any particular meaning.

Consequently, it is possible to deduce leadership knowledge from common pool water resources to community collective action or apply leadership theory from community collective action to common-pool resources. Actors' behavior is structured by institutions and if the collective choice institutions are similar, it is possible to apply leadership theory directly between different problem domains. I consider operational institutions more important in creating the drive for change than the process of change itself. Thin yellow lines in figure 1.1 are portraying the application limitation caused by choosing different collective choice rules.

Another aspect of studying CPRs is the tool that is used for analysis. Modeling and simulation of users of a CPR with agent-based modeling is among recent progress that has been made. Researchers have successfully created a simple agent-based model which can replicate the emergence of institutions by users deciding a rule or an institution collectively (Ghorbani & Bravo, 2016). A study of institutions which can lead to sustainable CPR management was done using the agent-based model and it was validated using datasets of CPRs institutions gathered from different case studies (Ghorbani, Bravo, Frey, & Theesfeld, 2017). These studies work as a proof of concept that it is feasible to model institutional settings of CPRs and replicate real-world results.

Case study analysis of the emergence of community-based management of water common-pool resources is time-consuming and hence, it limits the number of case studies that can be done. The number of factors and time horizon over which these factors need to be measured also limits the effectiveness of case studies. Experiments in the field or a game require considerable limitation of factors and scenarios under analysis. In such situations, modeling can provide a virtual laboratory to examine a greater number of factors and scenarios (Ghorbani et al., 2017). These approaches are complementary and insights gained from any of them can support and help advancement in other approaches.

This research is inspired by a case, however, I aim to develop a hypothesis, which can answer the main research question, and test it using agent-based modeling as the virtual laboratory. This is the focus and the core of this study. The modeling approach chosen here is agent-based modeling because it is suitable for modeling decision making, the institutional setting, and interactions of a high number of actors involved.

A single case is studied through available literature. An expert on the subject who is also from the same region as this case is interviewed as well. An expert on water resource management, who is the external supervisor for this thesis, is consulted to provide a wider view of CPR institutional settings and to validate the results of the modeling part. The case study is complementary to the core part of theory and modeling.

The case study is in Mojen, Semnan, Iran. In 1963, people of Mojen with the leadership of the head of the village created a new system to distribute water from the river for irrigation and they also built two Qanats (Rajabpur, 2011). For this purpose, they created a company and sold its shares to farmers (MoosaviNejad, 2006). These shares are still tradeable. Every shareholder can buy water rights for each year, which are also traded during that year (MoosaviNejad, 2006). This region is considered a dry area and there are 1200 hectares of farms (Rajabpur, 2011). Considering the age of this governance system and the fact that it has remained in place throughout the 1979 revolution and all changes in higher-level regulations, it can be considered a stable and robust governance system. Currently, everything happens under an established set of rules through the company they created. What is relevant for this study is the system characteristics and the process through which this collective action started and the company established.

The modeling approach in this study is somewhat different from some other agent-based models of the emergence of institutions like analysis of the emergence of institutions in water temples (Lansing & Kremer, 1993). In the study of water temples of Indonesia, a simple concept was used in which villages copy neighbors' successful pattern of irrigation and agriculture, therefore, what emerges is the dominance of a successful strategy, which in my opinion does not capture the full complexity of social-ecological system present. Similarly, studies by Ghorbani and Bravo (2016) and Ghorbani et al. (2017) model emergence of institutions through the transformation of strategies to rules, in case enough agents are in favor of the mentioned strategy. Ostrom (2010) also pointed out to the necessity of embracing the complexity when a simple model does not present the necessary process. To clarify, I am not denying the usefulness of models such as water temple study, however, I'm pointing out that for the intended goal of this study, complexity – to the extent that is necessary to explain human interactions resulting in collective action – should be included.

To achieve the goal of this proposed study, I will answer the main research question using the sub-questions that follows:

1. How can the leadership be identified in the context of initiating collective action in communities?

2. What is the role of leaders in the initiation of collective action in communities?

3. Is it possible to observe the described role of leaders in the initiation of collective action in the case study?

4. Which characteristics of a social-ecological system are relevant to the impact of leaders in initiating collective action in communities?

5. What model formalization can adequately represent the emergence of leadership in the context of the initiation of collective action in communities?

6. What are the most significant characteristics of a social-ecological system in the emergence of leadership in the context of initiating collective action in communities based on the model outcomes?

Even by answering the first two sub-question it is possible to answer the main research question, however, the rest of sub-questions help me to create a more complete and reliable answer. Answering these sub-questions will provide the needed insight to answer the main research question.

1.2. Research method

In the first step of this study, an extensive literature review is done to answer the first two sub-questions. They are answered in chapter 2. For this purpose, I analyze studies on community collective action, community leadership, leadership for the management of CPRs as well as organizational leadership. This chapter ends with a theory developed for leadership for community development. I will further improve it by using the insights that I gain from the modeling phase.

To answer the third sub-question, the articles done about the mentioned case study are reviewed, mainly to find relevant factors, institutions and the role of leaders in the emergence of the new water management system. Moreover, I interviewed a local community member who is also a water expert and has experience in working with communities from different areas in Iran on improving water management. The interview is based on the theory that is developed for the emergence of leaders in the initiation of collective action in communities. The aim is to see if the core concepts of this theory can be observed in the case. The case, as shown in figure 1.2, is an inspiration for the theory and the model of this research and I do not use it for historic validation of the model (neither based on data or pattern).

To give a structure in answering the fourth sub-question, SES framework is used. It helps in identifying and structuring factors and institutions that are important in the emergence of leaders in initial stages of collective action in communities, specifically in the context of common pool water resources.

Using these steps, I create the necessary knowledge base to model the emergence of leadership. At the end of chapter 4, I discuss the choice of concepts and factors that are used in the model.

Last two sub-questions of this research, which relate to creation and use of the model, are the subject of chapters 5 and 6. Appendix A is a detailed description of how the model was developed from scratch to the final version used in chapter 5. If the reader is not curious about this process, there is no need to go through this appendix and chapter 5 provides enough information.

Modeling of the concepts is done in steps. The first step starts with making a formalized simple narrative of the main concepts and factors which I chose at the end of chapter 4. I implement this formalization in NetLogo. This results in the first model. I analyzed the base scenario of the first model and preliminary experiments based on some simple hypotheses to see if results are as expected and explainable. I find the shortcomings and use them to improve the model conceptualization. This conceptualization is again formalized and implemented to create the second model. I do a similar process to create the final model. Hence, there are three major modeling steps. To clarify, each modeling step ends in a complete working model. At each step, the new implemented concepts are verified to make sure the model is performing as it was intended based on the developed theory. In the end, the model is used to find significant factors that affect the emergence of leadership which I present in chapter 6.

Lastly, in chapter 7, I present the conclusion and limitations of this study. I discuss and reflect on the process and findings of the research in this chapter as well.

The research method of this study is illustrated in figure 1.2. In this figure, discussion and conclusion chapter is not written since it is a synthesis over all steps.

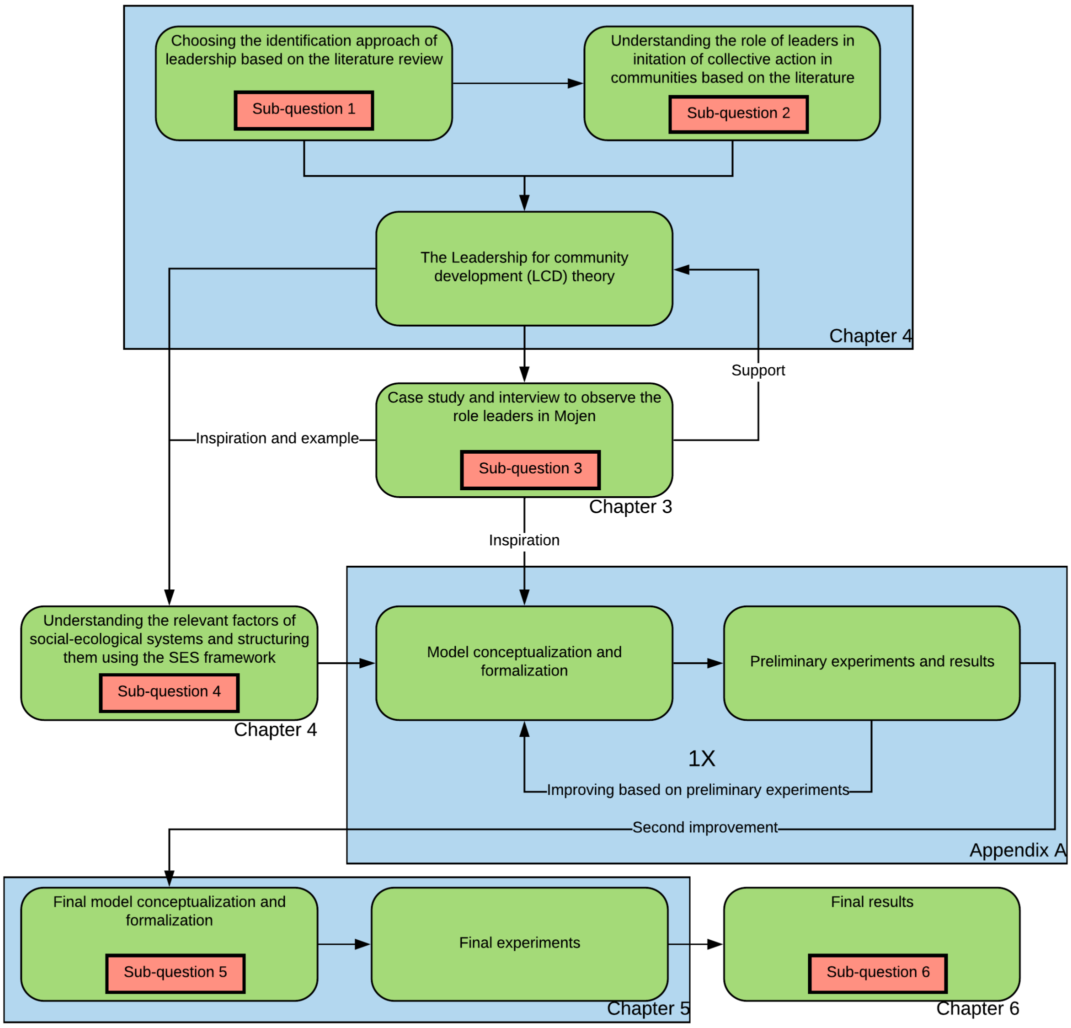


Figure 1.2: Research flow of this study

2

Leadership in communities

Leadership is the focal element of this study. To understand the role of leaders in the emergence of community-based governance, first, leadership and characteristics of leaders should be defined. In this chapter, I build the necessary framework and propose a theory to explain the emergence and the role of leaders in initiating community-based management of resources.

Collective choice rule of a community, which relates to its culture, shapes how collective decisions are made, how collective action is performed, and how leadership manifests itself. Therefore, it is important to make clear what type of communities are the target of this research.

Operational rules specify how the system is managed and how much authority individuals have. At the same time, collective choice rules might give extra powers to some community members in the system over how the operational rules may change. In the literature, sometimes it can be seen that leaders in a community have authority and control over the use of the system and any change in rules (see Vedeld, 2000 and Quinn, Huby, Kiwasila, & Lovett, 2007), or in some social-ecological systems there is no authoritative power for any community member in creation or modification of rules (see Onyx & Leonard, 2011; Ricketts & Ladewig, 2008). Based on collective choice rules either all members of the system have the same decision making right regarding changes in operational rules or they don't.

Before going further I want to make a classification based on the differences in operational and collective choice rules and position this study with respect to them. I have chosen to study the role of leaders in the communities where:

1. the collective choice rules dictate equal decision-making rights for every community member for changing operational rules
2. and there is no authoritative (command and order) power in the management and use of the resource based on operational rules.

I made this choice because it seems to be the case in small communities which are interesting for this study (Harley et al., 2014; Martiskainen, 2017; Onyx & Leonard, 2011). To apply the findings of this research in a different subject of collective action in communities (i.e. other than community-based management of water resources), the second criterion should be changed to lack of authoritative power (based on operational rules) in that subject or domain.

As the first step, I specify the perspective and area of analysis for finding and identifying leaders in section 2.1. In section 2.2, I choose a definition of leadership that complements the identification approach and fits the context of this research. The next step (section 2.3) is focused on understanding the roles leaders play based on the chosen definition of leadership. To structure these findings, I will review an organizational leadership theory which acknowledges complexity in section 2.4 and discuss its implication for communities in section 2.5. In section 2.6, I synthesize and connect the concepts that I have decided to adopt for this research. In the final section of this chapter, section 2.7, I discuss if these chosen concepts of leadership in communities are relatable to Iranian rural communities since the case study for this research is in Iran.

2.1. The theoretical lens for identification of leaders

To identify leaders, it is necessary to choose a perspective or a theoretical lens and a definition of leadership. First I will start by specifying the theoretical lens. Researchers have suggested different ways to find and identify leaders in decision making or policy-making processes. Bonjean and Olson (1964) have suggested three main approaches for identifying leaders:

1. The first way that comes to mind is to look at the position. This view considers leaders as those who are in a position which has more decision-making rights than the rest. There has been contradicting results from case studies even for small communities (Bonjean & Olson, 1964).

2. The next approach mentioned by Bonjean and Olson (1964), which is widely used, is the reputational approach. This approach can be done in different manners but in its core, it requires asking people familiar with the community to name key individuals or people whom they see as a leader. The term *key individuals* has been used in some articles for referring to people who have the potential to be leaders or influence others. Critics of this approach reason that people might be wrong or being known as a leader does not necessarily represent decision making powers (Bonjean & Olson, 1964). It is interesting to point out usually these key individuals have certain jobs, occupation, and position in the community that depends on the context (Bodin & Crona, 2008; Bonjean & Olson, 1964; Sheikhattari, Burke, O'Keefe, & Bazargan-Hejazi, 2012).

3. Last approach Bonjean and Olson (1964) explain in their article is the decision approach in which a researcher analyzes actions in the process of decision making for an issue. This is very time consuming and it includes some prior assumption about which actions to include (Bonjean & Olson, 1964).

Another way for the identification of leaders that has some similarities to the reputational approach is by using social networks (see Bodin & Crona, 2008). In such an approach different metrics can be used to find key individuals from their position in the social network. The results of Bodin and Crona (2008) showed that some of the people in authoritative positions were not part of key individuals. This is in line with previously mentioned criticism of the positional approach. Using social networks can also show how leaders represent different subgroups of communities and how they are positioned among heterogeneous members of a community.

The four mentioned approaches are about where to look to find the leaders. The mentioned criticism of the positional approach is strong and it is not in line with the case studies of community leadership. I consider the reputational approach and social network metrics to show potential for leadership. The term *key individuals* highlights the same point. If one limit the area of analysis to actors who have the reputation or are in a good position (based on the network metric chosen) in the social network, he or she might miss leaders. Therefore, I choose the decision approach as the approach to identify and find leaders.

The way researchers try to find key individuals or leaders relate to how they perceive the concept of leadership. Based on my choice of identification approach, I need to find which actions should be taken into account and how to define leadership based on these actions. In the next section, I will explain some major and relevant definitions of leadership and make a connection with the chosen perspective.

2.2. Definitions of leadership

There are three relevant definitions of leadership considered here. Bonjean and Olson (1964) define two of them by presenting ideal types of leadership which are complete opposites:

1. The first definition of leadership concerns decision-making rights. The ideal type is a leader in a position who is only concerned with decisions related to that position while there might not be any group structure around the leader. Similar to this ideal type, Komakech et al. (2012) connected leadership to the heterogeneity in decision making power. This is called as political heterogeneity by Vedeld (2000). This perspective of leadership seems to be more aligned with the positional approach. Operational and collective choice institutions are of utmost importance in this definition.

2. The second ideal type of leadership is called "covert power elites" (p. 291). These types of leaders do not hold any official position and they are not known to the public while they influence different decision-making areas in collaboration with each other in a group structure (Bonjean & Olson, 1964). There is a body of literature which considers leadership from a hidden influential interaction point of view. Hunter had a great impact by his book *Community power structure: A study of decision makers* (Hunter, 1953), in which he argued it was powerful businessmen who ran a community and not the people in offices (Domhoff, 2007). This relates to decision approach of identifying leaders. In this definition, the importance of position and institutions are still applied, however, leaders are those who influence position holders.

From these two ideal types Bonjean and Olson (1964) mention four different characteristics of leadership structure as legitimacy, visibility, the range of influence and group cohesiveness.

The third definition of leadership discussed in the literature that I found relevant is overt influential interactions done to convince other actors or to sway them toward a vision or goal. Its main difference with the second definition is that there is no position. This act of influencing to change the opinion of another actor is considered leadership. R. B. Brown and Nylander III (1998) see leadership as a relationship in which leaders and followers both affect each other. This definition is also in line with the decision approach of identifying leaders.

In some studies, which use influential interactions point of view, leadership has been defined as an emergent property. This way leadership is defined as an emergent result of many influential relationships between community members (Pigg, 1999). Pigg (1999) argues that leadership is "not done to followers" (p. 200) and emphasizes the importance of understanding the process over who the leader is since leaders are results of the leadership process.

The first definition of leadership is dependent on the heterogeneity of decision-making rights, which I excluded at the beginning of this chapter. The second definition also assumes unequal decision-making rights. Moreover, it is important to note that in communities with different size, culture, and institutional settings, leadership structure will be different and my assumption is that in smaller communities there is less possibility for the existence of covert elites while even people at official leadership positions are not that powerful. I follow the third definition, not only because the others are not aligned with the focus of this study, but also because it is applicable to types of communities that are interesting for this study, it fits well to the decision approach, and it allows for an inclusive and complete analysis of leadership. Also, this choice implies consideration of leadership at the actor level.

I have chosen the identification approach and the definitions so far, yet, the influential perspective of leadership needs more clarification. To understand how leadership emerges, I need to know how influencing works.

Leadership as influential interactions

While both leaders and followers influence each other in this process, leaders' *power* is the distinguishing factor that allows an unequal influence through interactions which may result in a change in interests of followers toward common interest (Pigg, 1999). The power resources that leaders use for applying influence is explained by Rost (1993) as "reputation, prestige, personality, purpose, status, content of the message, interpersonal and group skills, give-and-take behaviors, authority or lack of it, symbolic interaction, perception, motivation, gender, race, religion, and choices, among countless other things. I call these things power resources. Influence does not come out of thin air. It comes from people using their power resources to persuade" (p. 160). von Rueden, Gavrilets, and Glowacki (2015) have also argued that community members might follow leaders or key individuals of the community, because of leaders' competency, prosociality, and prestige.

The stress over lack of authority or leadership labels in this view is an important point. A prominent element in the synthesis done by Pigg (1999) is the shared *vision*. This process of influencing is toward arriving at a shared vision and achieving it.

Pigg (1999) explains a transition from a leader to a manager happens as the collective vision of a community starts to be realized. This way, the management can relate to position while the leader becomes an issue of relationship, influence and public entrepreneurship.

Now it is clear how influential relationship works and the distinction between managers and leaders are expressed. Still, the purpose of influencing in the context of collective action should be explained. This makes the role leaders play through influencing other community members clear.

2.3. Role of leaders

Since leadership emerges through influencing and influential interaction happens through social networks, it should not be any surprise that the role of leaders is closely connected to the social network structure.

One of the most important abilities of leaders is to mobilize resources and activate collective action (Heekathorn, 1993; Ryan, 1994 cited in R. B. Brown & Nylander III, 1998) while development problems in rural areas are related to resource mobilization by leaders and their network (R. B. Brown, 1991 cited in R. B. Brown & Nylander III, 1998). This resource mobilization can be divided into internal and external. Leaders need to connect to the right people (more important than connecting to many people) and work as a bridge between community and external resources, or, they can be strongly connected to community members who can do so (R. B. Brown & Nylander III, 1998). R. B. Brown and Nylander III (1998) put great emphasis on leaders' network and the importance of information for development in rural areas for internal and external resource mobilization. In the view of R. B. Brown and Nylander III (1998) leadership institutions and structure are more important than who is the leader and important characteristics of leaders' network are diversity, density, and size.

Giest and Howlett (2014) in their study of necessary conditions for successful governance of commons give better structure to this idea of resource mobilization through networks:

- They claim that focus on rules and institution is not enough and networks and network leaders are essential for understanding the dynamics which leads to community-based governance.

- Social, political and intellectual capitals in a community are necessary for the emergence of community-based governance and they are related to collaboration, agreement, and creation of knowledge in a community respectively. I consider these capitals a structured way of referring to resource mobilization.

- Social capital which is related to the trust between members can be defined as "features of social organization, such as networks, norms, trust, which facilitate coordination and cooperation for mutual benefit" (Putnam, Leonardi, & Nanetti, 1994, p. 67 cited in Giest & Howlett, 2014). They consider this capital a precondition for the other two.

- Knowledge, skills, innovation capacity, and physical assets community members have can be considered their intellectual property (Giest & Howlett, 2014).

- They also argue that networks of interactions in communities are responsible for the creation of these capitals and leaders of community networks should be neutral and they activate important actors, mobilize resources, influence values, norms and beliefs as well as creating an environment for beneficial outcomes. Giest and Howlett (2014) see networks themselves as emergent behavior.

- Another factor in their analysis of networks is the features of ties. Weak ties are good for creation of knowledge and they are flexible while strong ties like kinship are good for creation of trust and influencing but obviously, they are not flexible, therefore, a mix of these kinds of ties are needed in the community.

Similar to discussion of social capital by Giest and Howlett (2014), Krishna (2002) (cited in Bodin & Crona, 2008) has expressed social capital as a requirement for collective action and leadership as a necessity to activate and use social capital. Moreover, Bodin and Crona (2008) conceptualized social capital as a combination of network features and conflict solving procedures. The network characteristics that they include are density, fragmentation, and bridging.

Based on the aforementioned studies, I perceive the role of leaders to gather the necessary capitals (resource mobilization) for the collective action through influencing and convincing community members. I add one more factor to the social, intellectual and political capital mentioned by Giest and Howlett (2014). It is material capital. It can money, tools, infrastructure, etc. By adding this capital I limit the intellectual capital to knowledge, skills, innovation capacity and other soft skills. The nature of social capital is somewhat different from other discussed capitals. It needs a longer time to form and seems more deep-rooted than the rest. Therefore, in my opinion, leaders will not able to improve social capital much.

I also agree with the aforementioned studies about the importance of social networks and the network characteristics they mentioned. However, the notion of network leaders by Giest and Howlett (2014) is not adopted for this research. It is already discussed in this chapter that I consider having a special position in social networks only a potential for leadership and influencing.

Many concepts are discussed so far. Leadership is an emergent influential interaction behavior and leaders are differentiated from managers. Social networks are pivotal in this concept. Yet, the concept of leadership in communities seems vague and unstructured. I will explain a leadership theory from an organizational point of view, which also embraces complexity, to give structure to these concepts and connect them in a meaningful way. This leadership theory is called complexity leadership theory

2.4. Complexity leadership theory

This approach argues that if organizations want to be successful in today's world, they need to be adaptive, and therefore, behave like a complex adaptive system (Uhl-Bien, Marion, & McKelvey, 2007). Uhl-Bien et al. (2007) claims that leadership models of top-down paradigm will not be able to stimulate learning and adaptiveness in an organization, where challenges are not technical problems which can be solved by existing knowledge.

This model recognizes three different types of leadership, namely, administrative, adaptive, and enabling, that may exist in an organization together, while leadership itself is differentiated from the leader (Uhl-Bien et al., 2007). In their model, administrative leaders are people with authority at higher *position* of hierarchy. Adaptive leadership is where learning happens and in this type of leadership, it is not easy to find who is a leader, since this is an emergent result of asymmetric interactions. The asymmetry here is an important concept and it relates to differences in authority and knowledge. Enabling leaders promote learning and help this newly learned knowledge be adapted to the main organization by working in between these two other sides. Enabling leaders in this model can have a position, such as middle managers. In this model, leadership is dynamic and a leader is the one that influences it and the types of leadership recognized can exist at any level of an organization.

Tension is considered as a stimulus of learning in this model (Uhl-Bien et al., 2007). According to Uhl-Bien et al. (2007) this tension can be internal or external. External tension comes from a change in the environment that requires adaptability on the organization's side and internal tension comes from the heterogeneity of agents, which if it is translated to interdependence, can be a force of adaptation. This resembles finding by Komakech et al. (2012) about the role of interdependence in solving collective action problems. They also claim that CAS adaptation capacity depends on the existence of such tension as well as the ability of agents to interact and interdependence between them. Furthermore, the tension in an environment empty of trust and support of other agents will not be fruitful (Uhl-Bien & Arena, 2018).

The way adaptive leadership is modeled in CLT seems to be just the result that has emerged from interactions of agents in an organization, as it is defined as “emergent change behaviors under conditions of interaction, interdependence, asymmetrical information, complex network dynamics, and tension” (Uhl-Bien et al., 2007, p. 309). I disagree with calling this emergence of adaptive behavior in a CAS as leadership. Indeed, admitting some problems in this conceptualization, this model was further improved by Uhl-Bien and Arena (2018).

Improved complexity leadership theory

Uhl-Bien and Arena (2018) moved adaptation of new knowledge under enabling leadership, adaptive leadership was renamed to entrepreneurial leadership, and it is responsible for the creation of new ideas and knowledge. Administrative leadership is relabeled as operational leadership which aligns better with the collective action literature. In this model enabling leadership is positioned between operational and entrepreneurship leadership. There is no assumption about the hierarchical positions of these three types of leaders in this model, i.e. entrepreneurial leader might be on the very top (Uhl-Bien & Arena, 2018).

Uhl-Bien and Arena (2018) assert that in a complex system, major changes happen in situations that are far from equilibrium. Complex adaptive systems move between stability and instability or disequilibrium and emergence happens in the disequilibrium phase (Plowman et al., 2007). Kuhnert (2001) believes “institutional setting are in permanently shifting disequilibrium” (p. 25) and argues that public entrepreneurs, whom I see as the enabling leaders in the improved CLT model, act in response to a shift in this settings. This shift in settings can be internal or external, and it can be regarded as the tension in the CLT model. Leaders of different phases of innovation are not necessarily the same, and indeed because of different dynamics and different required skills, they may need to be different (Uhl-Bien & Arena, 2018).

The role of networks in the creation of ideas is emphasized more as well. Innovation process happens in four phases (Damanpour & Schneider, 2006; Perry-Smith & Mannucci, 2017 cited in Uhl-Bien & Arena, 2018). These four phases are idea generation, idea elaboration, championship, and implementation. According to Perry-Smith and Mannucci (2017) networks play a role in all four phases. As explained by Uhl-Bien and Arena (2018) weak ties are better at the generation of new ideas through brokerage and a low number of strong ties are useful for idea elaboration (this resembles the argument by Giest & Howlett, 2014). Brokerage through networks can gather the required support as idea generators may need to use influence and legitimacy of key individuals to attract other members to the idea. In the final phase, network closure gives the necessary pressure for working in collaboration with others as well as boosting information sharing and reducing the uncertainty around what other members might do.

Using complexity leadership theory

Complex systems, depending on their structure, can be adaptive or not (S. L. Brown & Eisenhardt, 1997; Eisenhardt & Tabrizi, 1995 cited in Uhl-Bien & Arena, 2018), thus, although communities are complex systems, if they are managed authoritatively top-down, or by governmental command and control, they might not be adaptive. This is not to say any governmental intervention is harmful. Indeed, each sub-system is affected by the larger system which encompasses it.

Ostrom and Cox (2010) have also argued that a polycentric governance structure which includes both governments and communities can be superior to other forms of governance for solving problems such as CPR management. A model like the improved CLT can be used at different levels as observer dependency is a natural characteristic of complex systems. In a lower-level analysis using improved CLT model, operational leaders can be the head of the farmers, while on a higher level analysis the focus for identifying operational leaders may be at the governmental agencies that work with communities. The focus of this research is at the community level and I consider governmental agencies or any other organization outside of the community an external factor.

The CLT model is relevant for this study because communities are complex systems. Challenges like the creation of a new governance system for management of water commons in a community are, without any doubts, complex problems which don't have any straightforward solutions, as if they had, CPR problems wouldn't have existed anymore, or not to this scale at least. Furthermore, the tension mentioned in CLT can be mapped to the prerequisite of understanding there is a shortage of resources in a community for them to self-organize (Ostrom, 2009b). Other conditions such as interaction and interdependence usually will exist in communities to some extent.

The CLT model presents some interesting concepts that I adopt for this research. Any change starts with an idea and the innovation process elaborated in the CLT model allows for a better conceptualization of how leaders emerge to influence others toward a vision. The idea of differentiating between enabling and operational leaders are interesting and similar to the differentiation already mentioned between managers and leaders. Yet, this theory is about organizations and to apply it to communities some concepts need to be modified. In section 2.5, I provide a review on how researchers have tried to adapt this model to communities.

2.5. Complexity leadership theory in communities

Onyx and Leonard (2011) in a study of emergent development projects in communities applied CLT to analyze the role of leaders. They viewed leaders in a community as enablers or enabling leaders. Onyx and Leonard (2011) argue extensively against the assumption of authoritative leadership in such contexts. They referred to organic leadership as well as CLT to claim decision making happens through the network of community members. In their case studies, no command and control were observed. The leaders they observed had the role of supporting and enabling as well as disrupting and challenging the system balance. These leaders supported innovation as well (Onyx & Leonard, 2011).

Several leadership elements were identified by Onyx and Leonard (2011). They are embeddedness, shared decision making, open system, vision, management skills, succession procedure and lastly persistence. The first four elements are observed in other resources mentioned in this chapter as well. Being an open system is a characteristic of complex adaptive systems (Uhl-Bien et al., 2007).

These elements are discussed further based on the findings of different researchers:

- Embeddedness: Bonjean and Olson (1964) considered cohesiveness as a characteristic of leadership structure which can be used to describe different models of leadership. In CLT, connections that leaders have is of great importance (Uhl-Bien & Arena, 2018). Bodin and Crona (2008) used networks to find key individuals. Ricketts and Ladewig (2008) mentioned networks as the necessary basis for leaders to apply their influence. Moreover, resource mobilization is done through leaders' network (R. B. Brown & Nylander III, 1998). In the synthesis by Pigg (1999), leadership is done through interaction. Giest and Howlett (2014) considered networks a missing piece in CPR studies. Harley et al. (2014) viewed leaders' embeddedness as a measure of social capital. Harley et al. (2014) also raise the issue of inter-group and within-group connections. The former is a matter of cohesion while the latter relates to interference. People who act as leaders for change in a community are known by many community members and they are very active (Martiskainen, 2017). Visibility, which was also a feature of leadership structure according to Bonjean and Olson (1964), relates to the embeddedness element of leadership. It can be seen from the bigger picture that is created by these studies, this is the most critical element of leadership. *Leaders act in networks.*

- Shared decision making: Decisions are made after negotiations and brokerage that happens in the network (Onyx & Leonard, 2011). This relates to the culture of communities about how important decisions at the community scale is made. At the beginning of this chapter, I made a classification based on operational and collective choice institutions that points to this factor.

- Open system: Sometimes, communities seek help from outside, which can be a governmental agency or an NGO, to fill up the requirements they need (Onyx & Leonard, 2011). Based on findings of Vedeld (2000), if the connection to the external resource is used for personal reasons which are not in line with the interests of the community, the legitimacy of leaders will be undermined.

- Vision: As Pigg (1999) explained, influence is done to create a shared vision or a common purpose. Kuhnert (2001) believes public entrepreneurs have a vision of a future scenario which fits their interests. I see this element as something that can be passed by enabling leaders in the championship phase of innovation in improved CLT. Vision is the element which is framed and sold to other members. A very important point discussed by Harley et al. (2014) is that enabling leadership can be successful when there is a shared vision. I argue that sharing the vision is a task for enabling leaders. For example, because users of a common pool resource will only reduce their harvesting only if they know the current situation will end in irreversible overuse of the resource, an enabling leader first needs to create the vision of a problem.
- Management skills: These are abilities such as planning, assigning tasks, financial management, etc (Onyx & Leonard, 2011). Like other skills, this is not something leaders necessarily have to have, however, they need to have or establish a connection to the people who have these skills. This is most important for the implementation phase.
- Succession planning: This is not important in the early phases of innovation and community development project. Again, using the language of Pigg (1999), I consider this as an issue for management and not leadership.
- Persistence: There may be many barriers and the future is uncertain. To achieve the desired change leaders need to be persistent (Onyx & Leonard, 2011).

I find some elements described by other scholars missing here, namely, the innovation process, and the motivation behind wanting change. Moreover, the influencing process is not elaborated in studies in which researchers have applied complexity leadership theory on communities. Two of the mentioned elements relate to management instead of leadership. This is based on differentiation suggested by Pigg (1999). Being an open system is a characteristic of many complex adaptive systems. I don't find adding the open system as a core element of leadership convincing enough. Leadership might emerge inside a community without any external interaction.

I perceive embeddedness a vague term. For example, the concept of acting as a bridge in a social network, which was an important part of leaders' role according to R. B. Brown and Nylander III (1998), cannot be understood from this term. I prefer to express it as *criticality of the social network*. This terminology can also integrate the importance of tie strength in a social network.

One of the most important factors that I consider missing here is the reason why leaders emerge or influence toward a vision. Leaders might emerge due to the feeling of injustice or the need to represent the voice of a community (Gross, 2008), as well as ecological or economical interests (Giest & Howlett, 2014). Once more it is interesting to compare it with the public entrepreneurship studies. Public entrepreneurs might attempt to change the institutional settings because they want more power, to prove their ability, to feel superior, to feel different or to experience the joy of creation (Kuhnert, 2001). In the CLT model, it was expressed as the internal or external tension (Uhl-Bien et al., 2007). What matters, in my opinion, is how they frame their intention and how they act, not what their real motive is. Based on the findings of Harley et al. (2014) I would argue that the reason leaders emerge is contextual, and therefore, has lower importance in the conceptualization of the leadership emergence process.

The criticality of the social network, shared decision making, vision and persistence are the leadership elements that I adopt from the study by Onyx and Leonard (2011) for my research.

Despite these shortcomings, studies of complexity leadership theory in communities are very insightful in pointing out the role of enabling leaders in challenging the system, encouraging innovation and supporting change, as well as proposing some leadership elements. Yet, this needs further elaboration. This elaboration, which I will do by connecting the findings of different scholars mentioned in this chapter, is the subject of the next section.

2.6. Leadership in this study

I made many choices regarding different aspects of leadership in communities so far. To make them clear and understandable I list the core concepts that I adapt for this research here:

- To identify leaders I use the decision approach. This means I look at decisions and actions that lead to the final outcome in each situation or scenario.
- Leadership is the emergent result of influencing interaction done to change the interest of other community members toward a vision.
- The aim of this influencing is to gather intellectual, material and political capital necessary for initiation of collective action.
- If the social capital in the community is low, i.e. people are not connected (based on the network characteristics recognized by Bodin and Crona 2008) or they do not trust each other, the probability of transformation of tension to a new idea becomes lower but not impossible since people can build new connections based on interest.
- Content of the message (alignment of the *framed* vision and personal interests), the prestige of message sender, the strength of the connection between sender and receiver as well as the level and direction of interdependence between them affects the power of influence. This is the power of influence relationship which depends on the connection. So, even an individual has different powers in his or her connections. Rost (1993) mentioned many factors affecting the influence of a leader, however, it is not an easy task to integrate all of them. Surely, it needs further attention.
- The main elements of this leadership conceptualization are criticality of the social network, shared decision making, vision, persistence, innovation process (four phases of idea generation, idea elaboration, idea championship or promotion, and idea adaptation) and motivation for change. Regarding criticality of the social network for an actor, it is important to know how the actor is connected to different sub-groups and through what type of connection.
- I consider the focal leader for the emergence of behavior in a community to be enabling leaders who are also referred to as public entrepreneurs or social entrepreneurs in some other studies like Kuhnert (2001). Enabling leaders have the role of challenging the current system, promoting innovation, as well as pushing and promoting change. These roles happen through influential interactions as well.

This synthesis is the leadership framework of this study. Since the objective of this research is to explain the emergence and the role of leaders in the initiation of collective action in communities, to further operationalize this framework, I must elaborate how these concepts are connected to create a theory of leadership in communities. I call this theory Leadership for Community Development (LCD). According to Wilkinson (1991), community development is the process of increasing the adaptive capacity of communities. This adaptive capacity is through collective action and it is for the welfare of community members. This is my intended connotation of the chosen name.

Leadership for community development

As a result of a literature review, I have chosen to assume no individuals in a community have more decision-making rights, nevertheless, the power community members hold for influencing others may differ. I have used the model by Uhl-Bien and Arena (2018) and elaborations of Onyx and Leonard (2011) as an insight for this theory. Although there can be operational leaders, the focus is on a situation where there is no operational leader present in the beginning. Moreover, there is no entrepreneur leadership position in communities, however, it might emerge during the process of development.

At the core of this theory is tension or dissatisfaction. This is the motivation for change. Every process starts here. Dissatisfaction with the current situation is required to create new ideas. One of the impacts of enabling leaders happens here. Enabling leaders can show other community members the current state is not desirable through interactions. Tension, which results in dissatisfaction, may exist between subgroups of a community or it may be an external factor. Sub-group here means some members of a community who are strongly connected to each other. External tension can be caused by problems in the community or an image of a better economic or ecological future.

Due to this tension and exchange of information, it is possible for an entrepreneurial community member to create a vision of the future in which the tension is solved and how to get there. This is the starting point of the innovation process. She will try to elaborate on the idea and gather some support in a circle of strong connections. This elaboration doesn't mean that every detail is understood and solved, this still relates to the vision. Based on the case studies mentioned by Onyx and Leonard (2011), I consider elaboration in community development more than a phase and a continuing process. There can be more than one elaboration circle, for example, one focuses on the technical side and another one on financial issues. The enabling leader herself might work as the entrepreneurial leader in these circles or she is connected to one who can do this.

After an initial round of elaboration, idea championship (or promotion) will start by enabling leaders. In idea championship, enabling leaders will try to frame the vision and transform the individual interest towards and communal interest for achieving the vision. This will happen through influential interactions. It is possible for the enabling leader to use the influence of another community member (key individuals) in the persuasion of others. During championship phase, any change in the vision or emergence of new tensions may be accompanied by a round of elaboration. These influencing interactions of key individuals are considered an act of leadership. The amount of power for two sides of a connection is not usually equal. Key individuals are those who are more embedded in the community (i.e. have more connections or are connected to different sub-groups of the community) and hold more power in their connections.

In this process, social capital can be increased slightly through negotiation and interactions while political capital is raised when community members see this vision as a desirable future. Intellectual capital is increased when enabling leaders succeed in connecting and influencing people with the skills that are needed. Other requirements like money and assets (material capital) can be gathered internally or externally through bridging of enabling leaders or someone who enabling leaders are connected to.

When the requirements are present and there is enough political capital behind the vision (in case of equal decision-making rights based on collective choice institutions this means consensus) the implementation phase can start. In this phase, management is needed instead of leadership and management skills, an element recognized by Onyx and Leonard (2011), will become relevant. This manager is the operational leader in the model developed by Uhl-Bien and Arena (2018).

It is possible to have different people as the enabling leader when after some progress another entrepreneurial member of the community creates and promote a vision which is more desirable.

The final remark here is not to take the leadership models and theories discussed here as the panacea for community problems (Harley et al., 2014).

An imaginary example of these concepts

I will try to illustrate these concepts using imaginary examples. In a community, parents of local school's student are not happy about the physical condition of students. They are connected to teachers (interdependent weak tie) and by discussing this issue they cause tension. Teacher A by interacting with students' parents gets the idea of creating a sports center for school as a result of this tension. This was idea generation phase and there was no leadership involved. Teacher A brings it up in a school staff meeting. These teachers have cohesive connections together (strong tie). The idea is supported and elaborated, resulting in a shared vision between the teachers. They decide to try using an abandoned warehouse as the new sports facility. In this phase (idea elaboration) teacher A played the role of an emergent entrepreneurial leader.

This process continues in championship phase where they try to sell this idea to the parents. The only local physician is convinced that the idea is good by some of the teachers. She is a key individual in the system and many community members are dependent on her. Her job allows her to be connected to other key individuals as well as people who are required for implementation like the owner of the warehouse or a constructor. In this phase, teacher A is acting as enabling leaders but the physician has more legitimacy, influence, visibility, embeddedness and there is no ulterior interest seen in the physician's promotion which makes it way more useful for the process. After the vision is shared and the requirements like the budget are ready, implementation begins. In the implementation phase, a manager is controlling the renovation of the warehouse next to teacher A who is acting as the enabling leader. After it is finished, teacher B who was previously a pro-athlete becomes the manager of the facility. This is because reputation and different skills matter and the same person may not be deemed as a key individual in different fields. A gradual shift from leadership towards management is also present.

When this is finished, if there is an idea about a change in usage of the sports facility there might be a tension with the operational leaders present, while in the beginning there was no operational leader.

Nonetheless, these phases do not have to follow each other in this sequence. Imagine when teacher C is trying to promote the idea at the beginning of championship phase to few people, a parent express dissatisfaction with the idea because the facility is not going to be available to anyone besides the student. Tension is caused and an idea is generated that it can be open to everyone on weekends and the idea is supported by the people present (weak ties). In this scenario, a simultaneous idea generation and elaboration, both with weak ties, happened after two separate phases of idea generation and elaboration.

Besides tension, support is almost necessary for idea elaboration. There might be an exceptional leader who tries to promote an idea even without any starting support. However, if when teacher A tried to discuss the idea in a school board meeting, there was a lot of tension and no one supported the idea, it would have been the end of it.

Applying multiple streams model to leadership for community development

To clarify the core concepts of this theory, I illustrate them using multiple streams model of Kingdon and Thurber (1984) which I already explained in chapter 1. Figure 2.1 is the result of applying multiple streams model to leadership for community development.

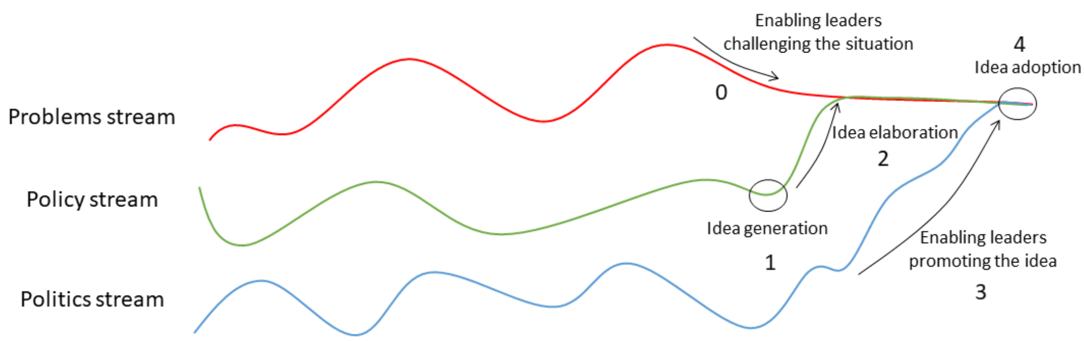


Figure 2.1: Multiple streams model representation of leadership for community development

Before any idea is created, enabling leaders may challenge the situation (0). This increases the attention the problem receives. As a result, people might become dissatisfied with their situation. This dissatisfaction may trigger idea generation by one of the dissatisfied agents (1). After idea generation, policy and problem streams do not coincide yet. Idea elaboration phase follows the idea generation (2) and if it is successful and idea creator receives support for the idea, enabling leaders emerge to influence and convince other community members to support the idea (3). This increases political capital (and other capitals if they are necessary). In the case of gathering enough support, the idea is adopted (4). Idea elaboration is about making the problem and policy streams match each other (this is called a problem window). Similarly, Idea promotion is the effort to make political stream meet the other two (this is called a policy window). This is a simple representation of leadership for community development.

I numbered the challenge of the current state by enabling leaders 0 because this is before the innovation process. Also, please note that there might be more than one enabling leader, and it is possible those who challenge the status quo are different from those who promote an idea. In the modeling part, the focus is mostly on the innovation process and the emergence of enabling leaders through the idea promotion phase. I made this choice because I perceived the innovation process more important than the challenging phase and also because they might be different leaders comparing to those who disrupt the situation. I call those challengers, problematizing leaders.

Applicability of leadership for community development

I do not claim this is the only mechanism that explains the generation of new ideas until their implementation but this is one mechanism which works. As an example with the same assumptions about operational and collective choice rules, imagine farmers in a branch, which is almost isolated location from the rest of irrigation branches, go through the process described here and adopt new small-scale water management in their own branch. Other farmers start imitating them because of their success. This is an example of purely *leading by example*. There was no necessity for communication and some farmers emerged as leaders through a completely different process. Obviously, if these assumptions about institutional setting are not true for a community, the leadership emergence might happen differently. For an example, see the case study by Vedeld (2000).

I started this chapter by expressing the connection between culture and collective choice institutions. I have taken collective choice institutions, as expressed repeatedly here, to enforce equal decision-making rights over changing operational institutions. This study is inspired by a case in Iran and I have studied the case and interviewed an expert regarding the case to check if it is possible to distinguish the leadership concepts discussed in this chapter (see chapter 3 for the results of this analysis and the interview). Now, the question is if the cultural setting in an Iranian rural community is in line with this assumption regarding the collective choice institutions. Therefore, I reviewed a rural case study in Iran in the next section.

2.7. Leadership culture in Iran

Since the case used for this study is in Iran, it is useful to become familiar with community leadership culture in Iran to support the conceptualization used here. Sheikhattari et al. (2012) tried to identify key individuals of two rural communities in Iran by interviewing local residents. The identified key individuals had varied characteristics in terms of age, education, religiousness, and occupation.

Sheikhattari et al. (2012) classified these people to three different groups of leaders, trustees, and celebrities. They explained leaders as the people who could urge people to participate in a development project, trustees as those who are protective of cultural norms and celebrities as role models who were successful in terms of achievements in sports, education or art. I see these three groups of key individuals different on their degree of influence, knowledge, and the scope of influence.

The findings of Sheikhattari et al. (2012) show that key individuals they identified as leaders, like educated teachers of the village, were better suited for development projects in comparison to respected elders who were considered trustees of the community. It seems people who were identified as celebrities are useful to borrow influential power to activate other community members in a project. These findings also support my assumption of lack of authoritative leader.

3

Emergence of leadership for community development in the case study

In this chapter, I aim to provide a proper picture of the case and to validate the existence of the main concepts of Leadership for Community Development in this case. Identifying the main concepts from the case supports the theory and provides an answer to the third sub-question. The structure of this chapter is in the same order.

3.1. Introducing Mojen case

There are some studies of the Mojen water management system but almost all of them are in Farsi. Unfortunately, they haven't followed frameworks such as the SES framework but still, some elements of this framework, like the action situations can be found out in these studies.

Mojen, its climate, population and the crops that are grown there were explained in chapter 1. Here, I will explain the old management system, the new governance system, and the procedure through which this changed happened according to studies that are done. Currently, water for irrigation comes from two rivers, two karizes, and multiple wells, however, at the time of implementing the new governance system they only used the rivers and at the same time, they built the karizes. Wells were dug at a much later time (Rajabpur, 2011).

In the old system, farmers were divided to 10 blocks based on the family relationships and every block was known by the name of the most prominent member (Bohlolvand & Sadr, 2007; Kiani, 2009). Based on what is recorded by MoosaviNejad (2006) irrigation happened in periods of 10 days in random order and each block could use the water for one day. The lands that belonged to farmers of each block were far from each other, thus, during each block's turn water had to be supplied to different and far areas which resulted in major water loss. Furthermore, it wasn't specified how the water will be distributed between different farmers of one block. All in all, this system caused a lot of conflicts, which would be worse in dry seasons. Small landowners were extremely unhappy with their share causing conflicts between them and big landowners. Big landowners also had conflicts among themselves. Rajabpur (2011) stated that in the old governance system, inter-block distribution of water was managed by a mirab appointed by the farmers of that block. Mirab is a complex Farsi word consisting of mir, meaning sir and ab which means water. This word remains used in the new water management system as well.

These conflicts and the feeling of loosing too much water were the factors that caused the emergence of the new management system (Rajabpur, 2011). The person that introduced the idea of the new system to the community was the head of the town at the time, who was also known as a smart individual and he had a connection to the central government since he was responsible for the distribution of subsidized governmental sugar (MoosaviNejad, 2006). This individual also had the knowledge of how to create a kariz (also known as a qanat) and suggested building two to increase irrigated land and overcome the shortage of water in drier seasons. To gather the necessary budget for creating two karizes, karizes' water share was given proportional to each farmers' contribution (MoosaviNejad, 2006). In the early times after the creation of the karizes, the water was used to irrigate only the close by farms, but with the improvement of water distribution system this water was combined with the river water and kariz water shareholders could get their water at any place (Rajabpur, 2011).

In the new system water right and land is separated (Rajabpur, 2011). To change the management system, each farmer's water right was recorded and used as the basis for the new management system (Bohlolvand, Sadr, & Hashemi, 2015). They decided to continue using time instead of volume as the measure for the water right of each farmer (Rajabpur, 2011). Kiani (2009) describes that Water is divided into 13 different sections which are managed by 12 mirabs with one head mirab. The water from each section irrigates farms one by one, starting from upstream towards downstream based on the water right that a farmer has. This procedure happens in periods of 12 days and each farmer only gets one turn and water rights from one period cannot be transferred to another period.

To manage the new system they decided to create a water distribution company. This company performs the following tasks (Rajabpur, 2011):

- Planning of water appropriation at the beginning of the year (based on the Iranian calendar),
- Water provision,
- Maintenance of infrastructure,
- Improvement of infrastructure,
- Monitoring,
- Punishing the rule breaker or suing them in courts,
- Solving conflicts,
- Bridging with external organizations,
- Financial management of the system.

These tasks can be seen as the main action situations in which the company is active in. Obviously, the action situation regarding electing the new management committee relates to the company as well. Rajabpur (2011) elaborates on these tasks as well. The planning of water appropriation is done by estimating how much water would be available during the irrigation season. As explained water provision is managed by mirabs based on farmers' water right which is printed on a yearly card for them by the water distribution company. Karizes and canals need maintenance which is done by the company. Moreover, in some wet seasons, the company succeeded to gather more money than they needed for operation, through selling the extra available water, which they used to build new canals, place pipes for water distribution or to improve the existing infrastructure. Using time-based water rights has made it easy to monitor the rule-breaking. Furthermore, Because the company is registered, it is easier for the management team to take legal actions against rule-breakers. The costs of company operations are calculated and divided based on the water share of farmers.

The management team of the company is chosen by equal votes of all people who have a share in the company (Kiani, 2009). The head mirab is either chosen by the company directly or through a call for bids. Then the head mirab chooses other mirabs (MoosaviNejad, 2006).

One prominent element discussed in theories of chapter 2 is the network. In Mojen, information is shared easily because it is a small community, there are many family relationships and local journalists are active (Kiani, 2009). It is interesting to note that according to MoosaviNejad (2006) even unemployed people of Mojen do not want to leave it for bigger cities, which might relate to the level of social capital in that community.

To get a better understanding of the system and the transition of the water management system, I decided to interview someone who is familiar with the case. The results are provided in the next section.

3.2. Interviewing a water management expert from Mojen

I interviewed Sadegh Rajabpur, a local from Mojen who works as social studies and water management expert in Mahab Ghodss company. Mahab Ghodss is a governmental consulting engineering company in Iran which works in the field of irrigation systems among others. His expertise in the subject was useful to confirm the proposed theories of chapter 2 beyond the case of Mojen as well. This interview was done on June 10th, 2019. It was a semi-structured voice call interview. By semi-structured I mean there were some main questions, however, I adapted and changed my question based on the information that was provided.

In this interview, I inquired more detailed information about the water management system in place, the older system, agricultural products of Mojen, how the change happened and the experience he has had in implementation of new water management and irrigation systems elsewhere. The material that is provided in the rest of this subsection is derived from this interview.

Wheat and potato are the main products of the region currently and back then, although, farmers change their main crop every now and then. In the new management system, the water distribution company is activated when the demand for water is high, water resources are limited and there is a possibility of conflicts between farmers. Therefore, in different years, the number of irrigation periods managed by the water distribution company is not the same. This way, they avoid unnecessary costs. Water rights are not related to the types of crops in any way. Usually, there are some seasonal water rights exchange deals between farmers with water demanding crops and those who have crops with lower water use. This is despite the fact that in the national regulations water resources are taken to be public property controlled by the government. This national regulation doesn't leave any room for legal water rights exchanges, nonetheless, water rights transactions are publicly done in Mojen and no one has tried to stop it.

In the starting days of the old system, farmers of each block were located close to each other, but as time passed by, people of Mojen started to buy and sell lands. As a result, people who belonged to the same block had lands that were far apart at the final years of the old system, which, as described before, caused a lot of water loss. Yet, that wasn't the only reason that made farmers dissatisfied. Some farmers had more power and used this power to gain more water. These people were satisfied with the status quo and stood against the proposed change that led to the new management system. Be that as it may, most of the people, including most of the elders, were unhappy about the situation.

Referring to his experiences in the implementation of new water management systems in different areas of Iran, Rajabpur stated there are always some people who are benefiting from the current situation and will stand against change. Sometimes, this opposition to change is so strong that leads to physical violence.

Unlike what is suggested by some of the articles on this subject, Rajabpur believes it is not clear who came up with the initial idea, although it is clear that the town chief (the one the articles suggested as the idea owner) and some of the elders elaborated and promoted the idea. Town chief, according to Rajabpur, was the most critical person and devoted himself greatly towards the adoption of the new system. As an example, he even sent messengers to people of Mojen who had migrated to other cities and regions to gain their support. He was very active in the community, influential and well-connected.

The people of Mojen have shown a high level of cooperation and social capital prior to the change in the management system as well. They collectively managed the public bath and the local mosque. Cleaning the irrigation canals was another collective task done by the people.

Rajabpur believes many initiations of changing water management systems fail because the proposed plan is not useful enough in solving problems, the local context is not taken into account, the proposed plan is focused on equality instead of fairness, or in periods of water abundance the institutions are not practiced and forgotten.

When I asked about the necessity of the presence of someone like the town chief of Mojen in similar cases, Rajabpur provided some examples to confirm this hypothesis. In particular, he gave an example of a case in Kermanshah province of Iran. It was a case where many attempts at implementation of a new irrigation system have failed. Rajabpur spent two years negotiating with the local farmers and officials to reach an agreement. Rajabpur stated that he has tried to play a role similar or even beyond that of the town chief of Mojen. He acknowledged this role requires a lot of self-dedication and sacrifice. He stated instead of a democratic process there is a need for a leader who pushes for the change, someone who plays the role of *facilitator*. He believed there is no need for consensus, as in the case of Mojen, there were people against the idea till the end, nonetheless, supporters of change were much more and the town chief himself was very influential as well. Interestingly, he mentioned that in some cases, he was only successful after gaining the trust of locals by showing examples of successful implementations of new water management systems or irrigation systems.

The facilitating leader that he mentioned is similar to the idea of enabling leadership that is discussed in this study. Moreover, I don't see any disagreement between having a leader who pushes for change and changing the system through a democratic process. Opponents of change bent to the pressure of others at the end and participated in the new management system. Surrendering to the will of the majority in itself is democratic in my opinion.

Learned lessons from the interview

In conclusion, some lessons can be learned from this interview. From this interview, one can observe two phases of idea elaboration and most importantly idea promotion from the four phases of the innovation process introduced in chapter 2. It was already known that idea implementation phase has happened successfully.

Regardless of who actually came up with the initial idea, the idea became known when the town chief and some of the elders starting to talk about it. Previously, it was said about the idea generation that it happens in a well-connected position in the network where a variety of people with different interests are connected to. It's not far fetched to guess that actually the town chief or one of those elders created the idea in the first place.

Rajabpur emphasized that the idea was very well-thought and many details were properly designed. This shows that the town chief and those elders worked on the elaboration of the idea thoroughly. Furthermore, the fact that promotion of the idea is known to be started by a group of people implies that in an elaboration phase initial support was gathered.

In the promotion phase, the town chief proved to be very dedicated and worked very hard on gathering support behind the idea. In his work, the interviewee has practiced promotion of ideas for both the local population and the local governmental stakeholders.

Adoption of a new system requires a certain level of political capital, which is not necessarily the general agreement of every community member. It doesn't mean those who have been against the new idea until the end will be defecting immediately.

The final lesson learned from the interviewee's experience is that it is possible for an outside actor to take the responsibility of the first three phases of idea generation, idea elaboration, and idea promotion.

4

Understanding the context of leadership emergence in communities

The focus of this study is on the emergence of leaders in communities through the initiation of community-based management of water resources. Water resources and users together are social-ecological systems. Social-Ecological Systems can be defined as social systems where some agent interactions are done indirectly through agents' interactions with the ecological system (Anderies, Janssen, & Ostrom, 2004). From chapter 1 and 2 it must be clear that the emergence of a new governance system is contextual and highly depends on the ecological system. To understand how this emergence happens, it is required to know what factors of social-ecological systems or actions affect the outcome of interest and how these factors and actions are interrelated. Many of the relevant characteristics of social-ecological systems which are important in the emergence of leadership in the process of initiating collective action in communities are already discussed in chapter 2. Here, I want to present them in a structured manner. The SES framework, which was shortly introduced in chapter 1 can be helpful here. I use Mojen case to illustrate the relevant attributes of this framework.

For this end, first, I explain the SES framework in more details than what has been mentioned before. Next, I discuss actions, factors, and institutions that I deem relevant to this study. In the end, I will illustrate factors, concepts, and institutions that I will use in the modeling phase.

4.1. Explaining the SES framework

I shortly introduced the SES frameworks in the first chapter. At the core of this framework is the action situation. SES framework was built based on the IAD framework (Ostrom & Cox, 2010). The SES framework (see figure 4.1) can help researchers to identify a set of factors that would affect the outcome of the social-ecological system under study (Ostrom, 2009b).

These two frameworks were combined by McGinnis (2010) and the major point of this combination is adding the focal action situations which are a network of action situations where outcomes are produced by these interrelated action situations (Ostrom & Cox, 2010). The revision of the SES framework done by McGinnis and Ostrom (2014) will be used in this study. It's important to note that the SES framework is trying to present a dynamic process, not a static picture.

In the SES framework, there are four entities or components. These are resource systems, governance system, resource unit and the community of actors or agents. There can be more than one of each of these entities. In this study the focal resource unit is water and the resource system can be a kariz (qanat), an irrigation system, a river, groundwater, etc. Two factors that are outside the box in figure 4.1 are external factors that affect the social-ecological system under study but at the same time can be affected by the social-ecological system as well since complex systems have no clear boundaries. Any boundary assumed, as logical as it might be, is arbitrary and not absolute. Social, economic and political setting

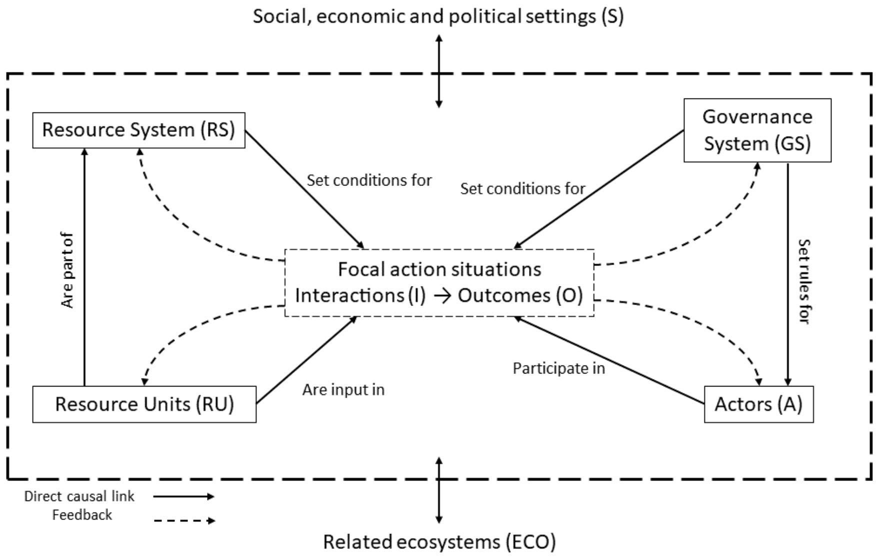


Figure 4.1: SES framework. (Source: adapted from McGinnis and Ostrom 2014)

include factors like the demographic trend. For example, if there is constant migration to the system

In action situations, actors make their decision from options that are available to them based on the limits that are generated by governance systems or the resource systems. The interactions in action situations include harvesting, information sharing, the deliberation process, conflicts, investment activities, self-organizing activities, network activities, monitoring activities, and evaluative activities. Outcomes can be measured by social or ecological performance or impacts on other social-ecological systems.

All of these entities are on the first level. They can be broken down to sets of attributes and again decomposed to sets of sub-attributes.

4.2. Relevant identified factors and actions

I chose some entities, attributes, and action situation here because I perceived them more closely connected to the role of *leaders* in *emergence* of a new resource management system and I illustrate them using the example of the case. The results of this section are not all included in the model and the model conceptualization requires more simplification of findings from chapter 2 and 4. These choices are explained in what continues and are represented in table 4.1. In this table, the code of each attribute as it was mentioned by Cox (2014) is written so the reader can look it up in that article.

I do not take the two external factors that are outside the box with dashed lines (in figure 4.1) into the account here.

The resource system and the resource unit are important because they create the reason and motive for change. In a case like Mojen, the resource systems (RS) is the irrigation system. Water used in this system comes from two rivers, two karizes (added with the new governance system) and some wells (relatively new). Water is distributed through natural and man-made canals which used to be unlined at the time of emergence of the new system (Kiani, 2009), causing major water loss. There was no water storage capacity either (Kiani, 2009). Location of karizes in relation to farmers can be important as well.

The resource unit (RU) will be water and it has heterogeneous temporal and spatial distributions. The heterogeneity of temporal distribution relates to different flows of rivers during different months and the spatial heterogeneity is due to the location-based limit of water

Table 4.1: Relevant attributes of SES framework for this study. A10, A11, A12, and A13 do not exist in the article by McGinnis and Ostrom (2014) and I added them here based on findings of chapter 2.

Entity	Attribute	
Irrigation system (RS)	RS1	Irrigation system (rivers, karizes, and canals)
	RS4a	unlined canals with high loss
	RS4b	Karizes
	RS3a	Flow of water from karizes
	RS3b	Flow of water from rivers
	RS8	No storage capacity
	RS9	Location of karizes in relation to farmers
Water (RU)	RU7a	Heterogeneous temporal distribution of river water
	RU7b	Heterogeneous spatial distribution of karizes water
Farmers (A)	A1	Population
	A4	Location of farmers for access to water resources
	A5	Key individuals, entrepreneurs, leaders and managers
	A6	Social capital is prerequisite
	A8	High dependence on the resource
	A10	Intellectual capital
	A11	Political capital
	A12	Material capital
	A13	Networks of farmers (interdependence or inter-group ties)
Governance system (GS)	GS4a	Common property (old system)
	GS4b	private property (new system)
	GS5a	Access to water in a random order (old system)
	GS5b	Access to water based on shares (new system)
	GS6	Consensus for collective choice
	GS8	Sanctioning and monitoring rules in the new system
Interactions (I)	I1	Taking water
	I3	Deliberation to elaborate ideas
	I4	Conflicts that may create a triggering tension
	I5	Invest to maintain or improve the system
	I6	Influencing activities
	I7	Networking to create connections and influence
Outcome (O)	O1	Successful and sustained governance system

access from the karizes in the early stages of a new management system.

The actors (A) are all farmers and because of their job and dependence of agriculture on irrigation in Mojen, the importance of resource is very high for them. Existence of key individuals as well as entrepreneurship, leadership, and management is the core attribute of this study and the one that is required, depends on the stage of the emergence of a governance system. Trust and social capital is the prerequisite of collective action. In the Mojen case, the location of farmers matters because of the irrigation system's structure. Here I added four attributes based on the findings of the previous chapter. Intellectual, political and material (e.g. money or physical assets) are needed for collective adaptation of a new idea. The collective action itself happens in a network of interconnected actors.

From the governance system (GS) what matters here are operational rules and collective choice rules. In case of implementation of ideas, operational institution such as monitoring and sanctioning rules become important as well. In Mojen, based on the old water management system people took water in their turn based on a random order. This is the old operational rule. The collective choice is based on consensus. In Mojen, before changing the management system the resource system could have been considered as common property, and afterward, the resource system or at least the water became private property as they can exchange their rights.

As an example of actions one need to analyze to understand the motivation for change harvesting and evaluation can be named. For example, each farmer evaluates current cost and benefits of different actions in various context to make a decision. From chapter 2, it is known that people like enabling leaders engage in influencing activities, networking, and deliberation. Conflicts may happen in the community which might lead to the tension that is the trigger for idea generation. Conflicts can also happen during the management of the new governance system, however, that is not part of the focus of this study. A management system may require monitoring and investment to maintain or improve the system and infrastructure. Finally, to implement a new management system of the resources, actors need to self-organize.

The outcome (O) of interest is a successful and sustained governance system. Based on the decision approach introduced in chapter 2, the final outcome of the system should be compared to relevant actions.

4.2.1. Adapting the SES framework to leadership for community development

In the process of developing leadership for community development theory, some concepts and factors were critical, while in the SES framework they are not explicit. Therefore, to properly connect the theory to this framework some improvements are necessary.

I understand that in the SES framework, the network of actors is considered part of social capital, however, considering its great importance, I find this representation of social networks insufficient. This social network is different from networks that are considered in the governance system entity according to McGinnis and Ostrom (2014). This is why I added A13, the network of farmers (or the social network).

Next, to the social capital, political, intellectual and material capitals may be required for successful collective action. This is not clear in the SES framework.

Another point of critique is the general presentation of leadership attribute. In the previous chapter, I made a differentiation between managers and leaders and expressed the need for different abilities in different stages of collective action from initiation to operation. From the review of literature mentioned in chapter 2, I consider the important attribute in early stages to be the existence of key individuals who have the power to gather the necessary social, intellectual and political capital, or in other words, those who have the potential to influence others towards the common goal. I find differentiating these stages and what is needed for each stage very important, and hence, I use four different concepts of key individuals, entrepreneurs, leaders, and managers.

With some improvements, it is possible to recognize important concepts of leadership for community development in the SES framework. Researchers interested in understanding the role and emergence of leaders in communities which use the SES framework, can record these variables and try to understand the outcome according to leadership for community development theory.

4.3. Choice of included factors and institutions in modeling

In the modeling phase, I intend to create a model of the emergence of leadership in the early stages of collective action toward community-based management of water resources based on LCD theory. The aim is not to model a common-pool resource and therefore, I made many simplifications regarding the ecological system. As a result, I include only one source of water (RS1) which doesn't have a temporal distribution and there is no storage capacity. Moreover, this chosen scope means that the outcome can be the success or failure of adopting a new system or idea.

Actors are farmers and their population is important (A1). To represent dissatisfaction of actors, which was critical in initiating the innovation process, farmers receive water (I1) from unlined canals with high loss (RS4a). The location of farmers (A4) and the flow of water from the source (RS3) becomes important as a result of these choices. Just to avoid burdensome complexity, I do not include conflicts. Dissatisfaction will suffice.

The social network of farmers (A13) is a critical attribute. Due to the scope and time limit of this research, I do not differentiate interdependence ties and kinship (or friendship) ties in the modeling phase.

Between the capital requirements, I only include the social capital implicitly (excluding the social network) and the political capital (A11) explicitly. I assume the social capital (A6) is high enough and leaders are trying to gather enough political capital (which is the consensus).

Before the emergence of a new community-based governance system of the resource, there are only key individuals. Key individuals are those who have distinct characteristics in comparison to other community members. Leadership is an emergent outcome (A5). I don't include entrepreneurial characteristics for the sake of simplicity. Management is not an issue of emergence of collective action and therefore, not included.

Collective choice and operational institutions

Finally, I need to make the institutional setting clear. There are implicit operational and collective choice institutions in table 4.1. The collective choice institution is easy to identify. As assumed in chapter 2, the collective choice rule requires consensus for a change in operational rules or other forms of collective action at the community level (GS6).

In the model, operational rules in place resemble the old system, that is every farmer gets water based on the farm size and the block (GS5a). Each block gets a turn to receive water. This implementation approach is not to replicate the case. Operational institutions have lesser importance and they just create the starting dissatisfaction. Innovation process can be toward creating a new operational institution. Furthermore, I don't include any exchange of water rights. I consider modeling the exchange of water rights more related to modeling a common-pool resource than to modeling the emergence of leadership, therefore water is the common property of all farmers (GS4a). Sanctioning and monitoring (GS8) are about the implementation and operation of a new system and are not used in modeling the emergence of leadership.

5
Modeling

In this chapter, I describe the conceptualization behind the model. The modeling paradigm used here is Agent-Based Modeling (ABM). The idea is to see the behavior of interest with minimal addition of complexity. In this study, I am modeling the *leadership emergence* in a community in the context of collective action for the management of water commons, not the *whole system*. At the end of chapter 4 I chose simplified representation of the findings from chapters 2 and 4, because, given the complexity and scale of theories and system components, as well as time limitation of this study, it is not possible to include all theoretical findings.

I believe that it's better to build the complexity step by step and have a good understanding of system dynamics, instead of a very complex system, whose results are not comprehensible and justifiable with high confidence.

The model in this study is intended to generate insights about the role leaders play in the self-organization of a community towards community-based management of common-pool resources. In this phase, continuing the thought process from the previous chapters, I will model the leadership process and the emergence of leaders in a community to implement an idea through the innovation process in the simplest way possible. Complexity is added in steps when deemed necessary. The model is built in three main steps. Only the last one is presented here. For a full understanding of the process through which the model is developed, these steps are presented in appendix A.

With this model, I provide an example of how the LCD theory founded in the second chapter can happen in a social-ecological system. Moreover, this can work as a proof of concept that the leadership emergence can be analyzed by agent-based modeling.

Here< I picture the start of collective action as reaching consensus to implement an idea which has gone through the four phases of idea generation, elaboration, promotion and finally implementation or adoption. The focus here will be mostly on promotion since this is where leadership patterns that are interesting for this study can be seen more prominently. Adoption phase, in particular, is not emphasized, since this relates to management paradigm in contrast to the leadership which is the center of this study.

As this study is centered around users of water commons, i.e. farmers, the problem owners are farmers. There might be external actors such as governmental agencies, NGOs or industrial water users, however, they are not included in this study.

5.1. Model conceptualization

The agent-based model created here needs to have farmers as agents and a representation of an ecological system which provides water to the farmers. Farmers interact with each other and the system in each time step. These interactions produce the emergent behavior of the system. Farmers are positioned in a social network. The model implementation is done in NetLogo and the aforementioned time step is called a tick according to this modeling environment.

The model is built to show how an idea about a problem, that is a source of *dissatisfaction* or tension is generated, elaborated, promoted and finally adopted and how leadership emerges along with these processes.

In chapter 2, I stated that in this study, leadership is seen as a process of influencing others. Throughout this report, due to the importance of influencing in this study and the model, the one who is influencing another person is called the influencer and the one who is the target of this action is called the subject. This is not to say in a pair of people only one can influence. Indeed both influence each other, however, they may have different influencing power. This act of influencing is intended to change interests of the subject towards a common interest, which is something that the influencer supports, or in other words, is *dedicated* to.

In this model, influencing is done to change the dedication of the subject toward an idea. Considering all these agents are farmers in a social-ecological system, an idea represents a proposed change in the ecological system (e.g. lining canals) or in the social system (e.g. new management system).

For this satisficing conceptualization of emergence of leadership trough the process of innovation (the four phases described before) in a community, following general narrative is needed.

General descriptive narrative

Some agents of the same type, which are farmers, exist in an ecological structure and are connected through a social network. The ecological structure provides access to the resource for the farmers. The resource is water. Water starts from a resource and is distributed through a network of canals. That is why I also call this ecological structure, an ecological network. Constant *water loss per step* reduces the available amount of water as it passes the canals to reach different farmers. Farmers are in different *branches* and *blocks*. The idea of using blocks is adopted from the Mojen case. This is not done to replicate the case, which isn't the purpose of this model, but to make sense of outcomes as well as creating an inefficient water management system which can be improved. To make it inefficient, farmers of the same block are distributed in different branches. This structure, as tested with the model, causes high water loss in comparison to a situation in which farmers of each branch are of the same block.

Farmers, of course, have a farm and they need water to utilize their *endowment*. Based on the farm size, there is a limit on how much water they can use, so if they get extra water it is just wasted. So in each time step, they have access to an amount of *allocated water* from which the amount they can utilize based on their farm size is called *usable allocated water*. This is determined by knowing *required water per unit farm*.

Farmers need a certain amount of water to pay for normal livelihood, named *minimum livelihood required water*. If they get more usable allocated water, they will be happy and if they get less, they will be dissatisfied. This is *water dissatisfaction*. Farmers might be dissatisfied for not fully utilizing their potential. This source of dissatisfaction is called *potential dissatisfaction*. Each farmer can only have one final value of dissatisfaction. For this purpose, *potential dissatisfaction limit* is introduced. If potential dissatisfaction is above water dissatisfaction and this defined limit, the final dissatisfaction of each farmer in each tick is potential dissatisfaction, otherwise, it will be equal to water dissatisfaction. A negative value for dissatisfaction is also possible and represents the satisfaction of a farmer about its current situation.

Dissatisfied farmers want a change, while satisfied farmers want to keep the status quo. The concept of innovation here centers around the phases an idea needs to go through. The first phase is idea generation. In this model, *idea generation possibility* of a farmer depends on its number of ties and dissatisfaction. The agent with the highest idea generation possibility is chosen to create the idea. This happens only if there is no known idea in the system and there is at least one agent with positive idea generation possibility (meaning it is dissatisfied). There is only one idea possible in this model.

If the idea generator supports the idea itself, the next phase happens immediately afterward, otherwise, the idea is forgotten and the next time step starts over. In the idea elaboration phase, the idea generator introduces the idea to its connections (other farmers that are directly connected to it through the social network). If half of them support the idea (a vote of majority) the idea is elaborated. Support for an idea comes from *dedication* of farmers toward the idea. Dedication comes from *personal conviction* of farmers about the idea and influences that they have been subject to. Until now there was no influence so this support is purely based on personal conviction. Personal conviction is based on dissatisfaction and preference of a farmer toward the idea. Preference of a farmer is basically if the farmer like the idea regardless of the situation or not. So, dissatisfaction and preference contribute to personal conviction. Somewhat obvious, satisfaction (negative dissatisfaction) reduces personal conviction. The personal conviction can be negative as well. The last factor used in determining personal conviction is the prestige of farmers. It means a prestigious farmer will think highly of its own opinion.

If the idea is not elaborated, that is not even half of the idea generator's connections support the idea, the idea is forgotten and the next time step will happen. On the other hand, if the idea is elaborated, farmers who are dedicated to the idea will start *exerting influence* on each other. By this process, new agents become familiar with the idea and their dedication (which is the weighted sum of subjected influences and personal conviction) changes.

In chapter 2 it was stated that the power of influencing depends on factors such as prestige and strength of connection or tie between the influencer and the subject. There were more factors, however, these two are chosen for the modeling phase. Another factor that contributes to influencing power is the content of the message. This is something perceived and evaluated by the subject. In the second chapter, it was argued that the influencer can frame the message as desired to have a higher impact but this is not considered here. Evaluation of the content of the message is conceptualized as personal conviction here. There is a factor added for this conceptualization of exerted influences. Dedication of an agent also contributes to its influencing power. This factor can be understood as an illustration of agents' willingness to utilize its influencing power along with how an influencer's dedication is received by the subject. To clarify, preaching an idea without much believe in it will be less effective.

In each step after every dedicated agent has exerted influence, the dedications of all agents are checked. If every farmer has a positive dedication, it is possible to say consensus or general agreement has been reached. For this purpose dedication needed to be separated to pre-dedication, at the beginning of each time step, and post-dedication, at the end of the time step. To rephrase, every pre-dedicated agent exerts influence and post-dedications are checked for consensus. The pre-dedication for the next time step will be the post-dedication of current one, if the total water, and as a result, dissatisfaction and personal conviction are not change in the next time step.

If the situation at the end of a time step is status quo, that is the sum of post-dedications has not changed tangibly, or one of the phases of the idea generation or the idea elaboration has failed, it means it wasn't possible to reach consensus at this ecological pressure. Therefore, the next time step will start with lower total water, while every variable in the model, except for the total water, is set to the default again.

Key performance indicators

Based on this conceptualization, the *ecological pressure* representing the relative reduction of the available resource, which is the total water in the system, can be a system-level *Key Performance Indicator (KPI)*. This KPI shows how much ecological pressure was necessary to trigger consensus in a community.

Another system-level KPI used in the model is the *consensus time*. Consensus time is the required time steps to reach consensus if the initial total water is set to the value that generates the ecological pressure necessary for reaching consensus (or simply called the final ecological pressure). Consensus time is less important the final ecological pressure as the system-level KPI, because it is more important to know how much pressure a community needs to reach consensus than the time it takes them to do so since consensus time would be meaningless if there is not enough ecological pressure felt by the community.

Yet the focus of this study is the emergence of leadership in the process of innovation for solving a community problem. Leadership of a farmer in the model can be seen as the *aggregate actual influences* of that farmer. This value is the change in the dedication of a farmer's connections due to the farmer's exerted influence on them.

This is truly leadership based on the definitions used in chapter 2. Leadership is the act of influencing others to change their opinion towards a common interest. However, aggregate actual influences is not a proper measure to show enabling leadership, which was the central point of leadership theory that I use here. To recap, enabling leaders are individuals who have a vision and are persistence toward reaching it. They influence others, through negotiations or other means, to gather the necessary capitals for adoption of the idea. In the conceptualization of leadership for community development, I consider enabling leaders as those who make gathering the necessary capitals for collective action, whether it is consensus or money, easier, hence, they are indispensable for the possibility of collective action. In this model, it will mean that an enabling leader is necessary to reach consensus at the same level of ecological pressure.

Personal conviction is chosen to represent the vision and persistence of enabling leaders. It represents vision because there is no change in the dedication of any agent without personal conviction. Exerted influences are like mirrors that reflect a farmer's vision or the vision that has reached it through these reflections (exerted influences). Furthermore, if there is no influence on a farmer, the farmer will only persist in the promotion of an idea if he or she is personally convicted to it. The dedication that comes from the influence and the pressure of others cannot be considered persistence. So the first agent-level KPI is *enabling leadership* and for each agent, it is the change in final ecological pressure if the agent was not personally convicted.

A similar idea is used to find *effectiveness* of a farmer's leadership. This is the change in the final ecological pressure if a farmer did not exert any influence, regardless if this influence is coming from the personal conviction of the farmer or the subjected influences, at all. By doing this, instead of looking at how loud someone has shouted (aggregate actual influences), it is possible to look at how effective a farmer has been in the community to reach a general agreement.

It might be somewhat obvious that something is missing here to complete the puzzle of leaderships. This became obvious from the initial model experiments as well. The question that gave rise to a new *type* of leadership was what is the difference between the effective and enabling leadership of a farmer? Imagine the idea is like a sound wave. Enabling leaders are like sound resources. Every dedicated agent, including enabling leaders, are also reflecting this sound (sometimes even louder). Here, some agents are more important or effective at this act of reflection, like an agent who is acting as a bridge between two sub-groups of a social network. Using the same metaphor I've chosen the name of echoing leadership for this emergent behavior.

The last two described types of leadership are not found in the literature and I added them as a result of observations made from the model. The word *type* here refers to the root of the behavior while the tangible outcome of all these leadership types is the same. This outcome is the change in ecological pressure as a result of this type of leadership. Enabling and echoing leaderships are two sub-parts of effective leadership and should be called effective enabling and effective echoing leaderships. The true enabling leadership, for example, is the aggregate actual influences that are caused solely because of personal conviction. However, this value is not important in comparison to effective enabling leadership, which directly shows the impact of enabling leadership on system-level behavior. Because of the adopted decision approach, only effective enabling leadership and effective echoing leadership are of importance here and the other two are not used, the word effective is dropped from their names for the sake of simplicity.

After developing the model conceptualization, I need to formalize it for implementation in NetLogo. In the next section, I present the model formalization.

5.2. Formalization of the concepts

Now that the concepts are generally introduced it is time to formalize them. As said before, farmers are ordered in branches. Their branch number is called column and the order in which they reside in a branch is the row.

The water distribution flowchart is presented in figure 5.1. As you can see water distribution happens block by block. There is no difference in the model behavior if the order of blocks is changed. In figure 5.1, two operational institutions are implicitly used. The first one dictates that farmers receive water based on the order of the block they belong to and based on the second one, farmers receive water according to their farm size regardless of possible water loss for those who are more downstream or their own need.

The total water (TW_t) itself is calculated based on the total farm of farmers ($\sum_a f_a$). This is done so that it is possible to make a comparison between different scenarios in which the total farm in the system changes. Relative definition of the ecological pressure (as you will see later) is for the same purpose. Aggregate farm multiplier (AFM) is defined per equation 5.1 for changing the total water based on the total farm size. Division by 10 in this equation is done to normalize everything according to the base scenario, in which there are 40 farmers each with farm size of 0.25.

$$AFM = \sum_a f_a/10 \tag{5.1}$$

Using equation 5.2 the total water at the start of the model $TW_{t=0}$ can be calculated based on the initial total water (ITW, which is constant over different experiments) and aggregate farm multiplier.

$$TW_{t=0} = ITW \times AFM \tag{5.2}$$

By doing this I've made sure that it is possible to logically compare different scenarios with a different population and farm sizes. This total water is divided between different blocks based on total farm size of farmers in each block (as described in figure 5.1).

Then water is distributed column by column (or branch by branch). To go from a column to another column or between rows inside a column, a step is taken and by each step, water is lost. Each column gets water based on the total farm size of farmers which are in that column and belong to the block that is receiving water to the total farm size of farmers of the block. A similar ratio is used to distribute water between farmers of a column. Since farmers of more than one block may reside in each branch, each branch may be used for irrigation more than once in each time step, therefore, increasing the total water loss.

From the allocated water, the usable amount needs to be known to find dissatisfaction. For this equation, 5.3 is used.

$$UAW_{a,t} = \min(AW_{a,t}, f_a \times RWUF) \tag{5.3}$$

where:

- $UAW_{a,t}$ is the usable allocated water of agent a at time t;
- $AW_{a,t}$ is the allocated water of agent a at time t;
- f_a is farm of agent a;
- and $RWUP$ is required water per unit farm which is a constant global variable.

Based on usable allocated water dissatisfaction is calculated according to equation 5.4.

$$WDiss_{a,t} = \max(\frac{MLRW - UAW_{a,t}}{MLRW}, -1) \tag{5.4}$$

Where:

- $WDiss_{a,t}$ is the water dissatisfaction of agent a at time t;

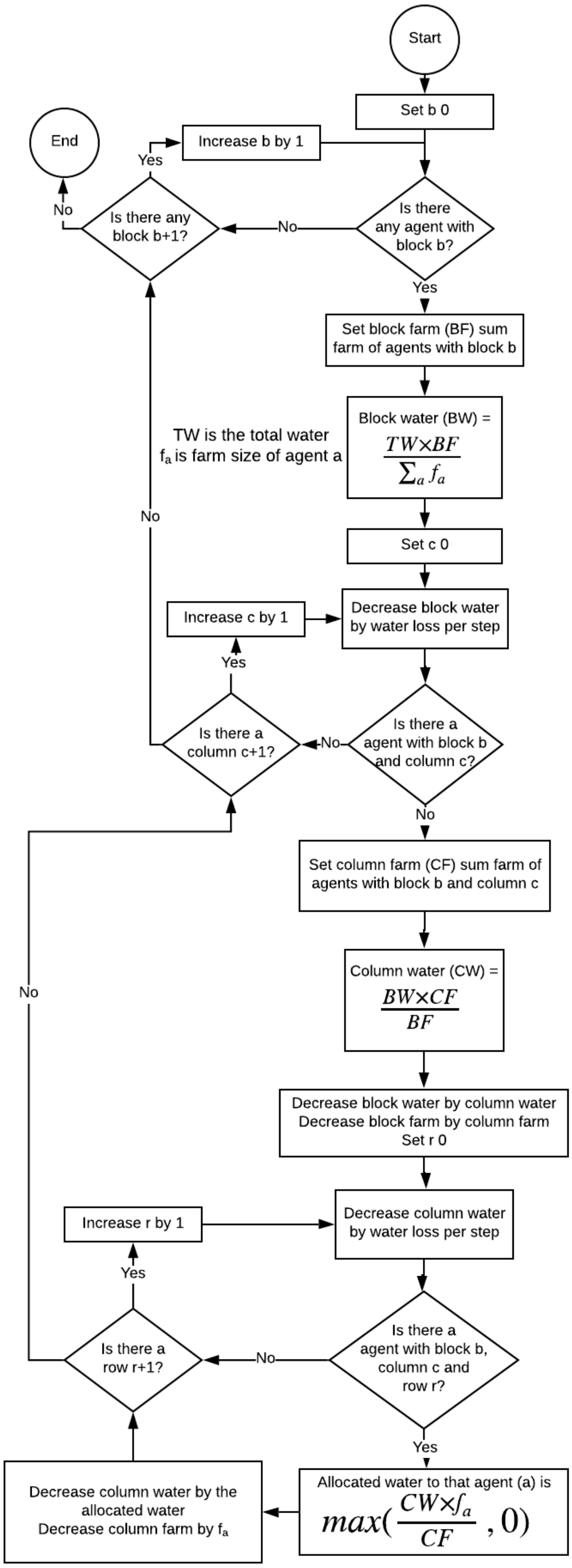


Figure 5.1: Flowchart of water distribution

- $MLRW$ is the minimum livelihood required water, it is a global constant and I use it to normalize water dissatisfaction.

By normalizing water dissatisfaction if an agent has twice as much as minimum livelihood required water or more is completely satisfied (-1 water dissatisfaction) and if it has no water it is fully (1) dissatisfied.

Potential dissatisfaction was the other source of dissatisfaction for an agent as described in the conceptualization section. Agent a has potential dissatisfaction at time t ($PDiss_{a,t}$) if it didn't receive enough water to fully use its farm.

$$PDiss_{a,t} = \min(\frac{RWUF \times F_a - AW_{a,t}}{MPRW}, 1) \tag{5.5}$$

It is normalized by maximum possible required water ($MPRW$) to be of the same unit as the water dissatisfaction. Maximum possible required water is the amount of water that an agent with maximum farm size in the model (limited to 1) may require to fully utilize its farm. So it is equal to the required water per unit farm.

Final dissatisfaction should be calculated based on these last two presented value. In the conceptualization, it was explained that if the potential dissatisfaction is bigger than a predefined limit and the water dissatisfaction, the final value of dissatisfaction of agent a at time t ($Diss_{a,t}$) will be equal to its potential dissatisfaction. Otherwise, it will be water dissatisfaction. That predefined limit is called potential dissatisfaction limit ($PDissLim$) and the mathematical representation of dissatisfaction is presented in figure 5.6.

$$Diss_{a,t} = \begin{cases} PDiss_{a,t} & \text{if } PDiss_{a,t} \geq PDissLim \wedge PDiss_{a,t} \geq WDiss_{a,t} \\ WDiss_{a,t} & \text{otherwisse} \end{cases} \tag{5.6}$$

The innovaion process first starts with the idea generation. Idea generation possibility for each agent at time t ($IGP_{a,t}$) is based on equation 5.7.

$$IGP_{a,t} = Diss_{a,t} \times NT_a \tag{5.7}$$

In this equation number of ties (NT_a) is a dependent variable that is just calculated by counting the number of connections for each agent. This is not a variable of agents or a global variable. In case of multiple agents having the same maximum idea generation possibility in the system, the agent furthest away from the source is chosen to generate the idea. This is implemented for full replicability of scenarios.

Next is the time for idea elaboration. Idea elaboration is based on majority rule of idea generator's connections. They vote based on their personal conviction. Personal conviction of agent a at time t ($PC_{a,t}$) follows equation 5.8.

$$PC_{a,t} = (\eta_{Diss} \times Diss_{a,t} + \eta_P \times P_a) \times Ps_a \times fam_{a,t} \tag{5.8}$$

Where:

- η_{Diss} and η_P are constant global weights and they sum up to 1;
- P_a is the preference of the agent a towards the idea (there is only one idea included in the system);
- Ps_a is the prestige of farmer a
- $fam_{a,t}$ is the familiarity of agent a about the idea. This is zero initially and when an agent comes up with the idea, participate in the elaboration process or is subjected to influence is changed to one. In the case of failed elaboration, the value will be set back to zero for all.

As described before, for practical reason dedication is separated to pre-dedication and post-dedication in each time step. They follow equations 5.9 and 5.10 respectively.

$$PreDed_{y,t1} = \eta_{EI} \times \sum_{x,x\neq y} EI_{xy,t0} + \eta_{PC} \times PC_{y,t1} \tag{5.9}$$

$$PostDed_{y,t1} = \eta_{EI} \times \sum_{x,x\neq y} EI_{xy,t1} + \eta_{PC} \times PC_{y,t1} \tag{5.10}$$

In these equations:

- η_{EI} and η_{PC} are global constant weights and their sum is one;
- $EI_{xy,t}$ is the exerted influence from agent x (influencer) on agent y (the subject, for which pre- or post-dedication is being calculated).

Only pre-dedicated agents exert influence. Exerted influence of agent x on agent y at time t ($EI_{xy,t}$) follows equation 5.11.

$$EI_{xy,t} = (\eta_{Ps} \times Ps_x + \eta_{TS} \times TS_{xy}) \times PreDed_{x,t} \tag{5.11}$$

In this equation, $x \neq y$ and TS_{xy} is the tie strength between the influencer and the subject. It is a variable of the link between agents.

To find the aggregate actual influences of an agent $AAI_{a,t}$, first, the actual influence of agent x at time t on agent y $AI_{xy,t}$ is needed. This value shows how much dedication of the subject (agent y) is changed because of the exerted influences of agent x at a time step.

$$AI_{xy,t1} = \frac{(PostDed_{y,t1} - PreDed_{y,t1}) \times (EI_{xy,t1} - EI_{xy,t0})}{\sum_{z,z\neq y}(EI_{zy,i,t1} - EI_{zy,i,t0})} \tag{5.12}$$

where $x \neq y$. This equation allows knowing how much of a subject's change in dedication is because of exerted influences from a specific agent. This equation accounts for the possibility of the full dedication of agents, that doesn't really happen.

The aggregate actual influences ($AAI_{x,t}$) of agent x at time t is the sum of all actual influences on different agents over time (equation 5.13). The initial value for this variable is zero.

$$AAI_{x,i,t1} = \sum_{y,x\neq y} AI_{xy,i,t1} + AAI_{x,i,t0} \tag{5.13}$$

The most important KPI of the model is the ecological pressure. It follows equation 5.14.

$$EP_t = \frac{TW_0 - TW_t}{TW_0} \tag{5.14}$$

The other four KPIs need more detailed explanation. To find out these KPIs each model run is divided into four phases. The first one is the normal run. Everything happens as it is explained so far. The next one is *checking consensus time*. In this phase, every variable is set back to the default of the same scenario except for the total water. It is kept at the last recorded value. This way the model starts with the necessary ecological pressure. The rest of the model follows what explained in conceptualization and formalization.

The agent-level KPIs are found similarly. Echoing leadership depends on enabling leadership and effective leadership (equation 5.15), hence, two extra phases are needed for these KPIs.

The third phase is enabling leadership. In this phase for the number of agents in the model, the model is run again from the default setting, except for the total water, until reaching consensus. The only difference is that in each run, an agent's personal conviction is set to zero. The final ecological pressure at the end of each run is compared with the final ecological pressure at the end of the normal phase. If the final ecological pressure is more, it shows that the agent whose personal conviction was set to zero for this run, had a positive effect on the system-level behavior and without its enabling leadership it is more difficult to reach consensus. Effective leadership is found with the same idea, however, except for setting personal convictions of agents to zero, they are not allowed to exert any influence on any agent even when they are very dedicated. By having these two leadership indicators the last one is calculated based on the following equation.

$$EcL_a = EfL_a - \max(EnL_a, 0) \quad (5.15)$$

Where:

- EcL_a is the echoing leadership of agent a;
- EfL_a is the effective leadership of agent a;
- And EnL_a is the enabling leadership of agent a.

There might be cases when consensus is not possible at all. This only happens if there are agents that are isolated from the rest in the social network. In such cases, the consensus time is reported zero and the final ecological pressure is one. In some other cases, there might be an agent who is acting as a bridge between two sub-groups of agents in the social network, which wouldn't be connected if it wasn't because of this bridging agent. In these cases, the consensus is not possible if the bridging agent doesn't exert any influence. In these cases, the echoing leadership of the bridge is reported as one.

Consequently, the narrative of a model run for each scenario is like the following:

1. All input variables are set to the default value of the scenario;
2. Phase is set to normal run;
3. Run once and save the value of the final ecological pressure as normal run final ecological pressure;
4. All input variables, except for the total water, are set to the default value of the scenario, and total water is set to final total water of normal run;
5. Run once and record the time steps it takes to reach consensus as the consensus time;
6. Set phase to enabling leadership;
7. All input variables, except for the total water, are set to the default value of the scenario, and total water is set to the final total water of normal run;
8. Run once for each agent as the candidate and save the difference between the final ecological pressure and the normal run final ecological pressure as the enabling leadership of the candidate;
9. Set phase to effective leadership;
10. All input variables, except for the total water, are set to the default value of the scenario, and total water is set to the final total water of normal run;
11. Run once for each agent as the candidate and save the difference between the final ecological pressure and the normal run final ecological pressure as effective leadership of the candidate;
12. Save the difference between effective leadership and enabling leadership of each agent as the echoing leadership of that agent.

By run once I mean the process described in conceptualization and formalization. Figure 5.2 also shows the flowchart of how this happens in the model. In this figure, the process of distributing water is what was presented in figure 5.1. In figure 5.2, dissatisfaction calculation process is a simplified representation. Figure 5.3 is the flowchart of how dissatisfaction calculation process is implemented. In figure 5.2, the lowest decision process, which checks for consensus or lack of water, is the model representation of my assumption of the collective choice institution.

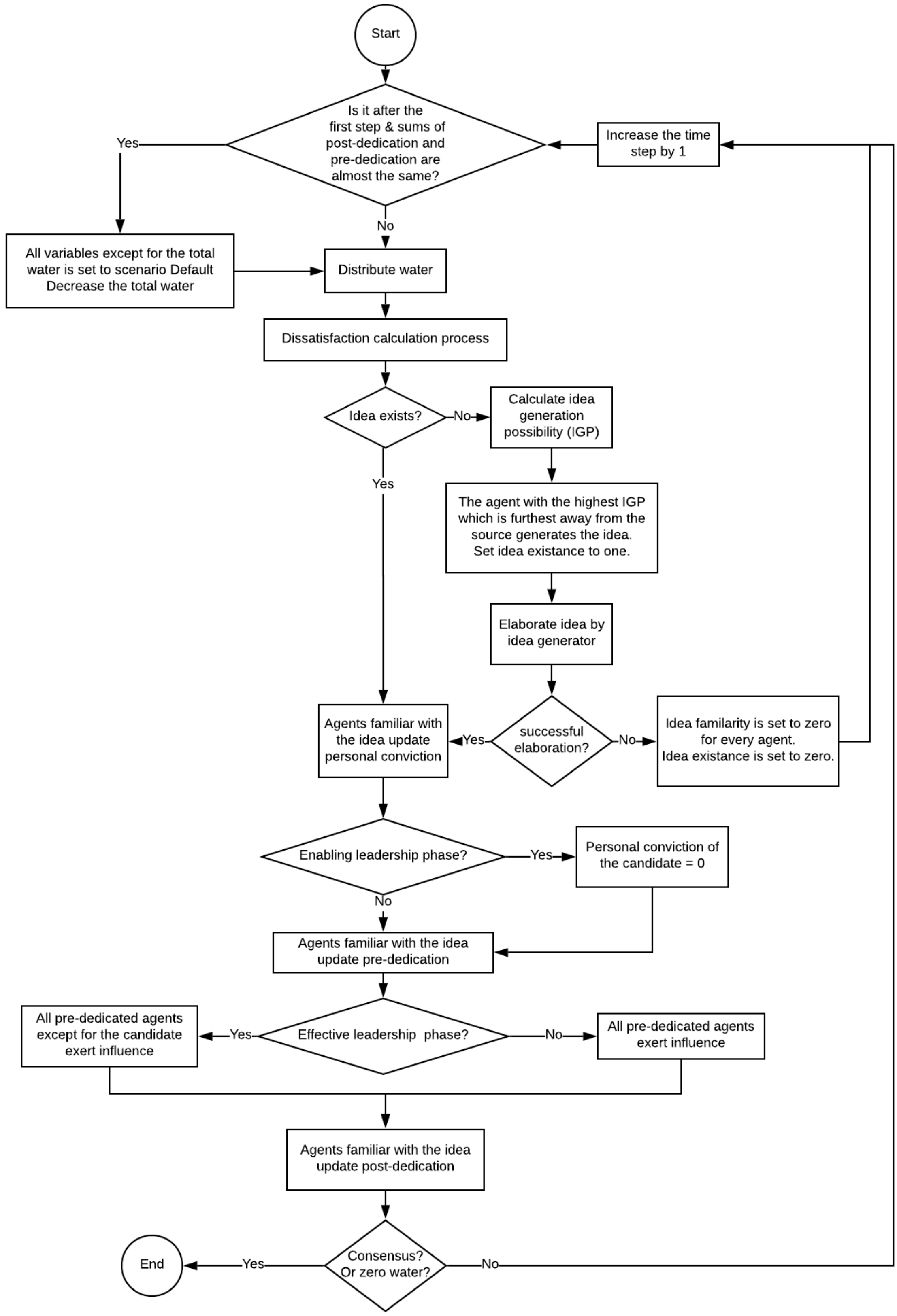


Figure 5.2: Flowchart of the model (run once)

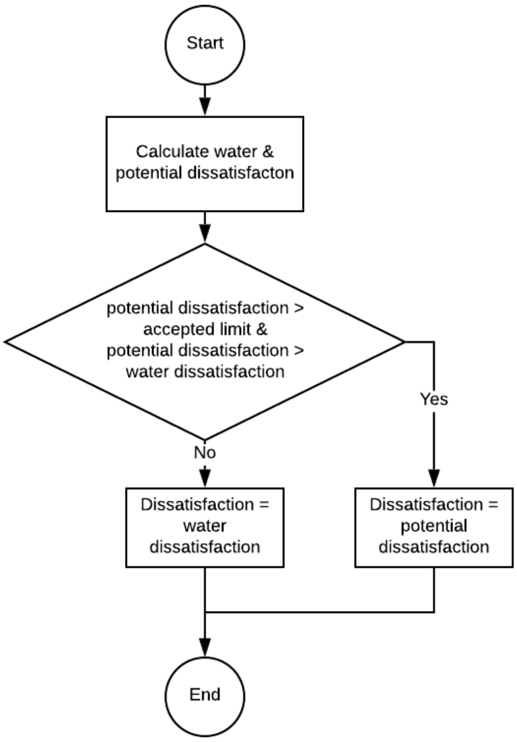


Figure 5.3: Flowchart of dissatisfaction calculation process

During the model steps, different sets of outputs were defined. The set of outputs presented in figure 5.4 is a result of this process. This is the sets of output that I've come to decide are most relevant for the hypotheses described later in this chapter. Regarding the hypothesis one wants to check, different variables can be set to be the output of the model. In other words, even the current model can do much more than what I present in this chapter. I'm limited by computational power and the time available for a master thesis. I explain about this in the limitation section of the chapter 7 again.

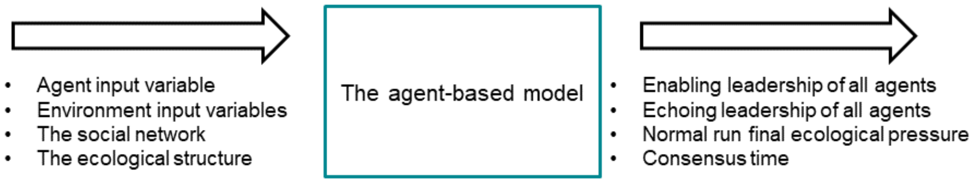


Figure 5.4: The model input and output variables

The input variables are those which are said to be independent in table 5.1. Tie and influence in this table (as the owner of the variables) are two types of links defined in NetLogo.

Table 5.1: Variables used in the model

Name	Type	Owner	Independent?	Range
Initial total water (ITW)	Static	Global	Yes	15
Water loss per step (WLS)	Static	Global	Yes	0.02
Required water per unit farm ($RWUF$)	Static	Global	Yes	2
Potential dissatisfaction limit ($PDissLim$)	Static	Global	Yes	0.15
Minimum livelihood required water ($MLRW$)	Static	Global	Yes	0.25
Weight of dissatisfaction in equations (η_{Diss})	Static	Global	Yes	0.73
Weight of preference in equations (η_P)	Static	Global	Yes	0.27
Weight of exerted influences in equations (η_{EI})	Static	Global	Yes	0.6
Weight of personal conviction in equations (η_{PC})	Static	Global	Yes	0.4
Weight of prestige in equations (η_{PS})	Static	Global	Yes	0.5
Weight of tie strength in equations (η_{TS})	Static	Global	Yes	0.5
Maximum possible required water ($MPRW$)	Static	Global	No	2
Aggregate farm multiplier (AFM)	Static	Global	No	$(0,\infty)$
Total water (TW_t)	Dynamic	Global	No	$[0,\infty)$
Ecological pressure (EP_t)	Dynamic	Global	No	[0,1]
Farm (f_a)	Static	Agents	Yes	(0,1]
Prestige (Ps_a)	Static	Agents	Yes	(0,1]
Column	Static	Agents	Yes	$[0,\infty)$
Row	Static	Agents	Yes	$[0,\infty)$
Preference (P_a)	Static	Agents	Yes	(0,1]
Block	Static	Agents	Yes	$[0,\infty)$
Echoing leadership (EcL)	Static	Agents	No	[0,1]
Enabling leadership (EnL)	Static	Agents	No	[0,1]
Effective leadership (EfL)	Static	Agents	No	[0,1]
Personal conviction ($PC_{a,t}$)	Dynamic	Agents	No	[-1,1]
Dissatisfaction ($Diss_{a,t}$)	Dynamic	Agents	No	[-1,1]
Pre-dedication ($PreDed_{a,t}$)	Dynamic	Agents	No	[-1,1]
Post-dedication ($PostDed_{a,t}$)	Dynamic	Agents	No	[-1,1]
Allocated water ($AW_{a,t}$)	Dynamic	Agents	No	$[0,\infty)$
Usable allocated water ($UAW_{a,t}$)	Dynamic	Agents	No	[0,2]
Idea generation possibility ($IGP_{a,t}$)	Dynamic	Agents	No	$(-\infty,\infty)$
Aggregate actual influences ($AAI_{a,t}$)	Dynamic	Agents	No	$[0,\infty)$
Water dissatisfaction ($WDiss_{a,t}$)	Dynamic	Agents	No	[-1,1]
Potential dissatisfaction ($PDiss_{a,t}$)	Dynamic	Agents	No	[-1,1]
Tie strength (TS_{xy})	Static	Tie	Yes	[0,1]
Exerted influence ($EI_{xy,t}$)	Dynamic	Influence	No	$[0,\infty)$
Actual influence ($AI_{xy,t}$)	Dynamic	Influence	No	$[0,\infty)$

5.3. Selected preliminary experiences of the final model

In the modeling steps, I did many experiments. Some of these experiments are important in the understanding of how the model works and what the results mean. Moreover, these experiments helped me identify which input variables are more important in determining system behavior. I repeated some of these experiments with the final model. In this section, I explain the experiments and in the next section, I will discuss their results. To avoid repeating what is already presented in appendix A, I will be very abstract in sections 5.3 and 5.4. By providing this summary, the reader is not required to read through appendix A anymore. However, for full description, please study appendix A.

Experiment setup

All of the experiments that are presented here use the same social and ecological network. This means the population of farmers (40), their connections, tie strength, block, row, and the column doesn't change in most of the following experiments. To elaborate, there are forty homogeneous agents placed in eight branches of five farmers. They have the same characteristics and each has six connections. Four of these connections are to others in the same branch and two are to agents from other branches.

Farm, prestige, block, and preference of all agents, as well as the strength of ties between them, are 0.25 in *the base scenario*. Each experiment only needs one replication since there is no stochastic input or decision process in the model. I have verified that seed number doesn't have any impact on the outcomes in these scenarios. In each experiment, except for the base scenario and the last two experiments, I make one agent a key individual. This means they have different characteristics regarding farm size, prestige, preference, number of connections or the strength of connections compared to other agents.

A slight difference in this model compared to the previous description is that when the model wants to calculate the enabling leadership of agents, the total water is set to the default value of each scenario. This way it is possible to calculate negative enabling leadership. The reason that is implemented here and not in the final experiments is that there is only one replication preliminary experiment. When higher number of replications are needed, this would have been much more computationally expensive. Negative enabling leadership represent barriers in the way of reaching consensus.

Experiments to understand the impact of higher preference of agents

In these experiments, one scenario was done per agent, in which only one agent has a preference of 0.5 instead of 0.25 which was used in the base scenario. The aim is to understand the impact of preference of agents in the model outcome.

Experiments to understand the impact of higher prestige of agents

In these experiments, I set the prestige of two satisfied and two dissatisfied agents to 0.5 instead of 0.25 which was used in the base scenario. In each experiment, I only changed one agent's prestige. The rest of the input variables are the same as the base scenario.

Experiments to understand the impact of stronger connections of agents

Three experiments were done for this purpose. In each of them, the strength of ties of one agent was set to 0.5 instead of 0.25 which was used in the base scenario. The rest of the input variables are the same as the base scenario.

Experiments to understand the impact of bigger farm size of agents

I performed eight different experiments. In each experiment, one farmer has a farm of 0.5. I chose both satisfied and dissatisfied farmers of the base scenario for this purpose. The rest of the input variables are the same as the base scenario.

Experiments to understand the impact of more connections of agents

I designed eight different experiments for understanding the impact of having more connections in comparison to the rest of the community. In the base scenario, each agent has 6 connections.

In each experiment, I add 7 connections to one agent, either with agents at the top of branches or at the bottom of branches. This differentiation is because agents at the top of branches are usually more satisfied than agents at the end of branches since upstream agents face less water loss. So, in four of these eight experiments, agents have 7 extra connections to the agents at the top of branches and in four of them, the opposite. Strength of these newly added connections is 0.25, like the rest of the connections.

Experiment to understand the aggregate impact of two key individuals

Imagine in one scenario making agent A a key individual (by changing farm, prestige, preference, number of connections, or strength of ties) reduces the final ecological pressure by X and in another scenario, making agent B a key individual reduces the final ecological pressure by Y. The question that I want to answer with this experiment is if making both agents A and B key individuals (by changing the same characteristics as the previous scenarios) in one scenario will reduce the final ecological pressure by $X + Y$. Therefore, I perform three different scenarios and compare the results. If these scenarios reject the hypothesis, there is no need for further experiments.

Separate idea generator, enabling leader and echoing leader experiment

Finally, after going through the preliminary experiments which were originally performed on the initial models, I like to present two (this and the next one) more specific scenarios which help with the understanding of different leadership types discussed in this report, namely, effective, echoing and enabling.

This experiment is aimed at providing an image of a scenario in which, the idea generator, the prominent enabling leaders and the prominent echoing leaders are different farmers. From the base scenario, it is known that the idea generator will be farmer 34 unless another dissatisfied agent has a high number of connections or there is a change in the farm size of agents. These changes are not done in this scenario, so the idea generator will be farmer 34. Farmer 30, who is in the same branch with the idea generator is chosen to be the echoing leader. For this purpose, this agent is given extra connections to other mostly satisfied agents on top of branches and the connection strength to all of its *friends* is increase to 0.5 from 0.25. This farmer's preference and prestige are also increased to 0.5. This is done to remove its negative enabling leadership and increase its influencing power respectively.

Farmers 28, 33 and 35 who are dissatisfied at the end of the base scenario are chosen to be enabling leaders. Therefore, they have a full preference towards the idea and they are well-connected (full connection strength) to farmer 30. Farmers 28 and 33 have connections strength of zero to every agent except for farmer 30. This way they depend on farmer 30 to convey their message. To prevent farmer 34 from becoming an enabling leader its connections' strength and preference of the idea is set to zero.

The isolated group experiment

I designed this experiment to provide an image of how the created virtual community would behave if most of the dissatisfied agents are isolated from the rest of the community.

To do this, I separated all agents at the end of the branches from the rest of the community. These separated agents are connected to every other agent in their isolated group of 8 agents. Then, I chose two agents from the isolated group to be connected to the rest of the community and act as bridges between two sub-groups of the community.

One of the agents in the isolated group, farmer 19, is connected to the next most downstream farmer in each branch. Furthermore, farmer 39, another agent from this group, is connected to farmer 5 just to avoid a full echoing leadership score for farmer 19. Farmer 5 is chosen because it is one of the most satisfied agents at the end of the model and it is one of the last ones to become dedicated to the idea. Therefore, farmer 39 cannot be a very effective leader and the role of bridging between the isolated group and the rest of the community will rest on the shoulders of farmer 19.

5.4. Results of selected preliminary experiences of the final model

I start this section by explaining the base scenario of the final model and my understanding of its interesting behaviors. Figure 5.5 shows the leadership indicators of the base scenario.

In the base scenario, the final ecological pressure for the base scenario is 0.1746 and the consensus time is 9 steps. Every time that there is no change between the post-dedication and pre-dedication of agents, the total water is reduced by 0.01. I chose this number by experimenting with the model to get a proper distinction between scenarios without making the model run too long. This choice results in 0.0006 increase in the ecological pressure every time the total water is decreased. The ecological pressure starts at 0 at the start of the model run in every scenario. To put the system-level KPIs that were mentioned here in perspective, I will compare them with the lowest and highest KPIs from the results of preliminary experiments. In these results, the highest ecological pressure is 0.1966 while the lowest is 0.1413. The smallest consensus time is 2 and the biggest observed consensus time is 12.

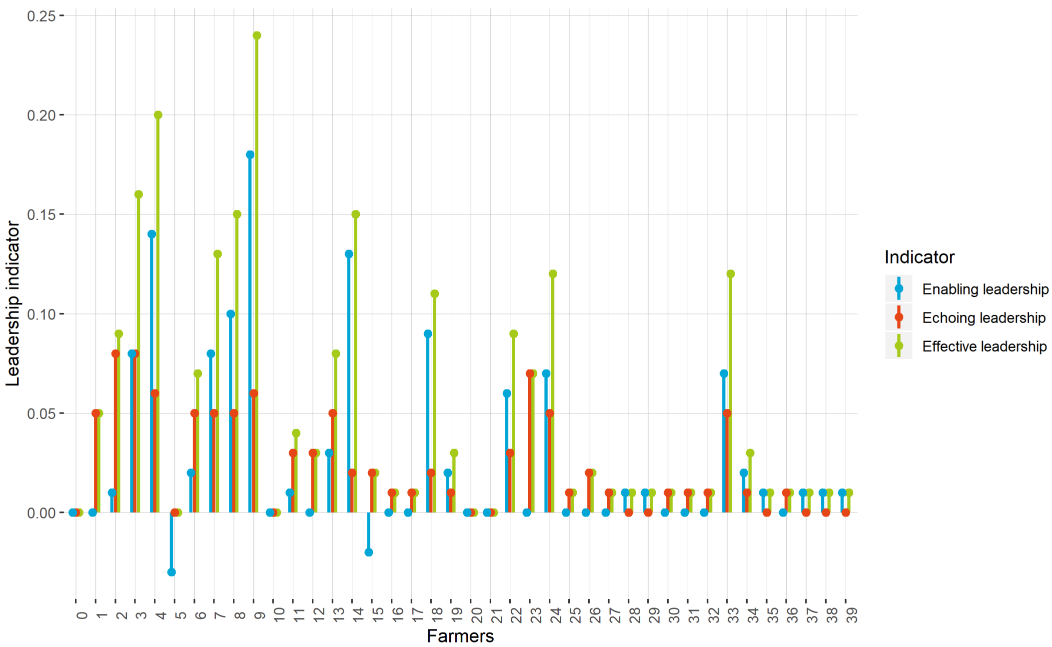


Figure 5.5: Leadership indicators of agents in the base scenario of the final model

One of the most important observations made was the fact that aggregate actual influences of agents are not connected to their effective leaderships or its sub-parts (enabling and echoing). Therefore, some farmers are influencing and leading while they are not effective or they are not enabling the community significantly towards reaching an agreement. The most significant factor that affects the leadership indicators (effective, enabling and echoing) is the social network. For example, to find the most effective leader between homogeneous agents, one need to find an agent who is dissatisfied (will be an enabling leader) or is connected to many dissatisfied agents (in this case it will be an echoing leader) as well as being directly connected to one or multiple of the most satisfied agents in the system who are not well-connected to other dissatisfied agents.

For example, in the base model, agent 34 is the most dissatisfied agent who even generates the idea, however, agent 9 and agent 4 are showing higher levels of enabling and echoing leadership. This is because they are very dissatisfied, connected to some of other very dissatisfied agents as well as being connected to two of the most satisfied agents. Agent 9 is connected to agent 5, who is the most satisfied and the biggest barrier (negative enabling leadership which was possible to calculate in the previous modeling steps) in the way of reaching consensus. The biggest barrier in the way of reaching consensus is not the most satisfied agent in all cases. It also depends on the connections of satisfied agents. All in all, it became clear that based on the conceptualization of the model, just being loud and influencing a lot is not necessarily effective.

It is also interesting to know that some of the agents might still be satisfied or have negative personal conviction towards the idea, yet, they yield to the influence of others. Therefore, I consider the behavior of agents in this model designed to be boundedly rational.

One of the emergent phenomena of the model is the feedback effect of influencing. Since all agents are influencing each other, an agent (let's call it B) who has become dedicated because of influences of another agent (let's call it A) influence agent A as well. As a result, agent A becomes more dedicated and the exerted influence of agent A on agent B increases in the next time step. This behavior creates a loop, which, in this model setup, is not significant for more than two time steps most of the occasions. This behavior can represent how dedicated agents can become more devoted by receiving support from other community members.

Aside from these interesting observations, the base scenario alone has three important implications for this research. First, it proves that it is possible to see the emergence of different leadership types discussed in this study, especially, the enabling leadership which was a core part of leadership for community development theory, using this model. Second, all dependent variables follow immediately from the equations, except for the leadership indicators. The effective leadership and the enabling leadership indicators are derived by neutralizing the influencing and personal conviction of agents respectively (it is important to remember that they are not removed from the system). That is why it is not easy to predict these values beforehand based on equations and input variables. In fact, lack of direct relationship between aggregate actual influences and these leadership indicators was surprising for me, however, the social network in each scenario can explain the emergence of these leadership types to a good extent. Lastly, the model is producing realistic and consistent results which increases my confidence in the validity of the model in respect to the theory.

The result of experiments to understand the impact of higher preference of agents

Between the agent characteristics, changing the preference of agents has the most straight forward outcome. As expected, it simply increases the personal conviction of an agent, might contribute slightly to its enabling leadership and overall makes reaching consensus easier (less time and less ecological pressure).

The result of experiments to understand the impact of higher prestige of agents

A prestigious dissatisfied agent reduces the needed enabling leadership of other agents while the enabling leadership of the key individual (the agent with higher prestige) is not changed in comparison to the base scenario. Consensus time and the final ecological pressure decreases. The echoing leadership of this prestigious agent, on the other hand, increases. If a satisfied agent has higher prestige in the system, it will become a bigger barrier on the way of reaching consensus.

The results from having prestigious dissatisfied agents in the model were not exactly as I expected and again the social network plays an important role in these outcomes.

The result of experiments to understand the impact of stronger connections of agents

When an agent has stronger connections in comparison to the base scenario, reaching consensus becomes easier. If this agent is a dissatisfied one who is connected to other dissatisfied agents, interestingly, a reduction in enabling leadership can be observed. This can be explained as sharing the burden of leading a community between close agents.

The result of experiments to understand the impact of bigger farm size of agents

The conceptualization of dissatisfaction in this model, causes an agent with a bigger farm to become dissatisfied, despite receiving more water than the minimum livelihood required water. It became clear from initial experiments that having an agent with bigger farm size contributes to reaching consensus at a lower final ecological pressure.

The result of experiments to understand the impact of more connections of agents

If a satisfied agent in the base model is given more connections, it will have a higher echoing leadership, which is even possible for agents who have negative enabling leadership. If a dissatisfied agent has more connections to other dissatisfied ones in comparison to the base model, this agent becomes a bigger echoing leader, while the enabling leadership of this key individual decreases. This is, as discussed before, a result of sharing the responsibility of leading. If on the other hand, a dissatisfied agent is given more connections to satisfied farmers, its enabling leadership increases. Given the results of experiments on the effects of the strength of connections, this outcome was expected.

The result of the experiment to understand the aggregate impact of two key individuals

From the initial experiments it also became clear that the system behavior in case of having two key individuals of A and B is not simply the exact numerical aggregation of model behavior in cases which there is only key individual A or key individual B. Of course if having key individual A helps to reach the consensus easier and key individual B makes it more difficult, reaching consensus in the system with both of these key individuals is neither as easy as the former, nor as difficult as the latter. I could not predict if the proposed hypothesis for this experiment would be rejected or not since the model behavior is the result of many interactions between all agents. However, these results reject the hypothesis and there is no need for further experiments.

Lessons learned from the combination of these experiments

When the ecological pressure in the system is very high, it can be observed that most agents do not show echoing and enabling leadership. In these situations, the general agreement seems unavoidable and no single agent has an important impact. However, if the ecological pressure is low, reaching consensus requires some agents with high scores on leadership indicators. Based on this observation, I created the hypothesis that there is a linear relationship between the leadership indicators and the final ecological pressure.

Based on the model conceptualization, the social network is of utmost importance and it is critical in explaining the emergent outcome of the model. This is consistent with the emphasize on the social network in the theory. Increasing the prestige, adding connections, or strengthening connections of an agent can create unexpected outcomes, which is possible to explain if one focuses on the connections of agents. Agents with these characteristics have higher *potential* for leadership. Therefore, they are truly key individuals.

These results allowed the design of final the next preliminary experiment. In this experiment I am showing my understanding of the mechanisms in the model.

The result of the separate idea generator, enabling leader and echoing leader experiment

The result of this experiment is presented in figure 5.6.

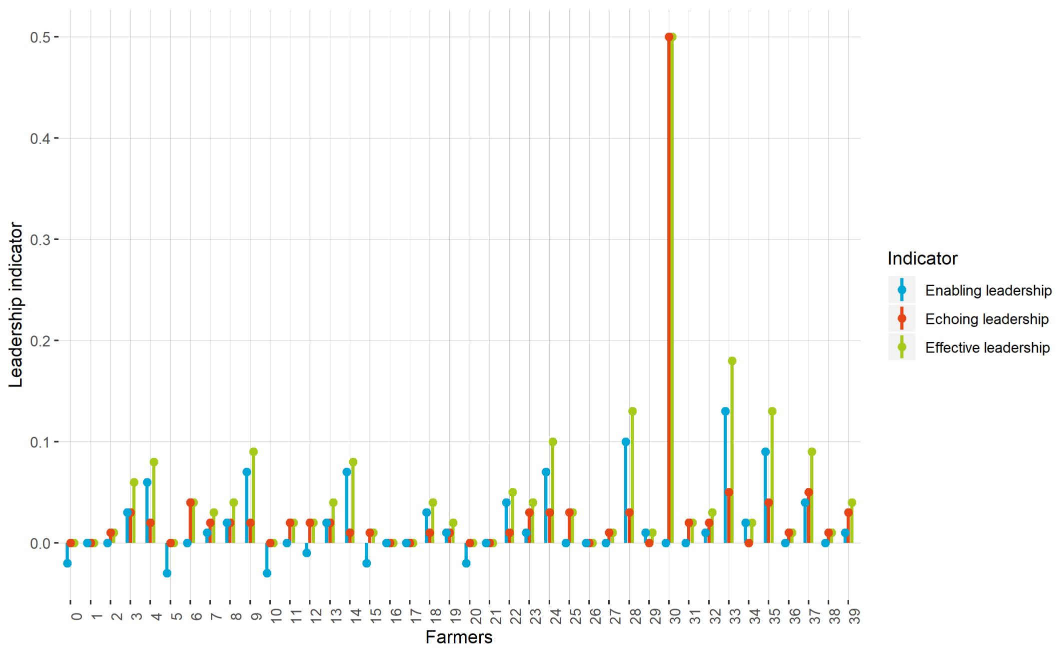


Figure 5.6: Leadership indicators of agents in the scenario where idea generation, the enabling leadership and the echoing leadership are roles of different agents

It is possible to see what I aimed for in this figure. So the story for this idea is as follows. Farmer 34 who is very dissatisfied came up with a new idea to change the system, however, it is not well-connected within its community and despite being very dissatisfied, because not believing much in its own idea, farmer 34 is less personally convicted than some of the other agents as well. Farmers 28, 33 and 35 hear about this idea directly or indirectly from farmer 34 and they like it very much. They are very convicted about this idea but most of them do not have proper connections to other agents except for being connected to farmer 30 who is both prestigious and well connected. Because of their close friendship with this farmer, they manage to persuade farmer 30 to promote their idea. Farmer 30 is convinced and plays a critical role in making the general agreement possible in a much lower ecological pressure in comparison to the base model. Therefore, agent 30 is showing echoing leadership, while agents 28, 33 and 35 are showing highest emergence of enabling leadership.

The result of the isolated group experiment

The narrative of this scenario is as follows. Since farmers of the isolated group are some of the most dissatisfied agents, they create the idea in very low ecological pressure and soon every one of them becomes dedicated to the idea. Farmer 19 conveys the message to the outside agents and brings back the support and feedback to the isolated group. However, due to this isolation, reaching consensus will be possible only at a very high ecological pressure. It is apparent that based on this conceptualization it will be more effective if agents can influence directly, instead of using a middleman. The leadership indicators of this scenario are presented in figure 5.7.

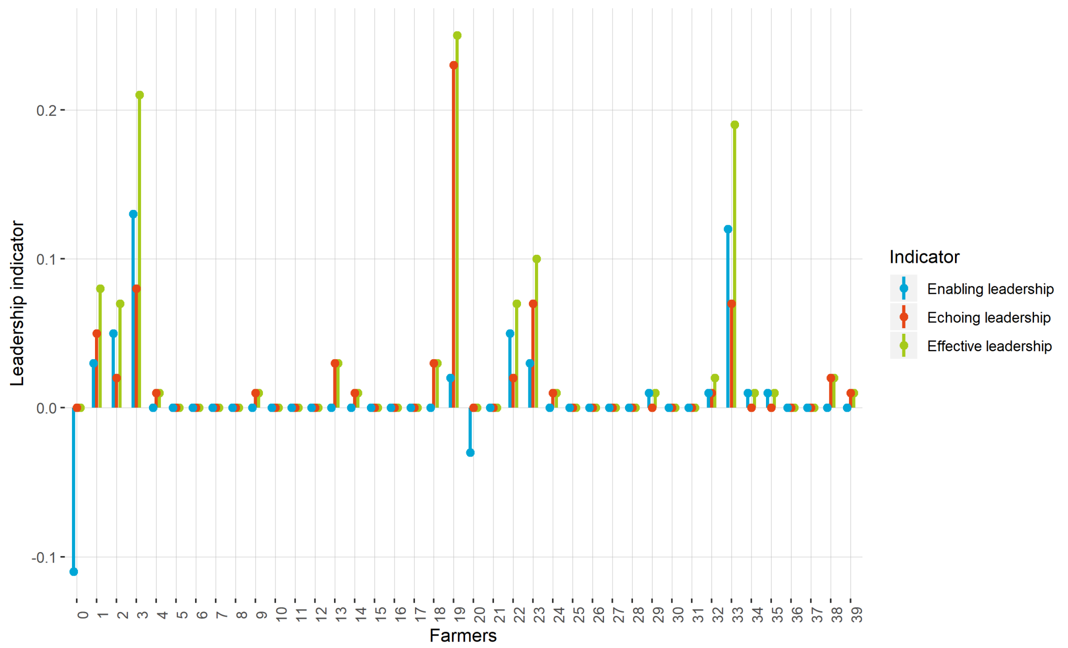


Figure 5.7: Leadership indicators of agents in the scenario where farmer 19 is the bridge between the isolated group (farmers at the end of the branches) and the rest of the community

Since all of the farmers in the isolated group are connected, if one of them doesn't influence anyone else, no big change will happen. Also, if one of them is not convicted, the others will influence it enough to overcome this lack of conviction in most cases (only agents 19, 29 and 34, as the most dissatisfied agents in this group, show slight signs of enabling leadership). Agents 33 and 3 are two of the most dissatisfied agents outside the isolated group that are connected to farmer 19, which is the bridge of the isolated group, therefore, they are both prominent enabling and echoing leaders of this scenario.

5.5. Verification and validation of the model

At last some discussion on the verification and validation of the model is needed. Since the model was implemented in phases, the verification was also done in 3 phases. These verification steps can be seen in appendix A. First, after creating the first model a thorough verification was done, and afterward, with every modification of the model, the added concepts were verified. Luckily, because of using the mathematical equation to develop a formalization of concepts for the model, model verification was very straight forward.

Regarding the validation of the model, I must say the model is an abstract conceptualization of the theory developed for leadership in chapter 2 and every factor and concept that are added are also included in the SES framework, as discussed in chapter 4. It is important to note that some concepts were added to the SES framework based on literature used in chapter 2, such as differentiating between leaders and managers as well as emphasizing on the role of social network on the emergence of collective action in contrast to implied social network in the social capital attribute.

All in all, every concept which I used here, except for the echoing leadership and the effective leadership which are my additions, has roots in literature. The abstract conceptualization and the design of this study don’t require field validation with recorded data. The preliminary experiments results, which was realistic, consistent with the theory, and followed immediately from the equations or it was explainable, validate the formalization of the model with respect to the theory. Moreover, I validated the concepts and mechanisms used here with a water expert, Prof. van der Zaag who is the external supervisor of this study. Sensitivity analysis is also presented at the end of appendix A.

Now that I have proved that the model can show the emergence of different types of leadership discussed in this research, the understanding of the model is increased as a result of the last section, and the model is verified and validated, it is time to use it to the fullest in the next section.

5.6. Final two sets of experiments

I chose some concepts that I saw to be most important, as explained why, to develop some hypotheses. Based on these hypotheses many experiments are done.

Bodin and Crona (2008) as well as Harley et al. (2014) considered the social network representation of the social capital in the system. Remember that in the SES framework presented in chapter 4 the social capital is a prerequisite of collective action. In the preliminary experiments performed, which were described just in the previous section, the social network plays a crucial role in determining the outcomes of the system. So the first set of hypotheses are focused on some network characteristics.

In the real world, farmers are not homogeneous. So, agent characteristics are changed to heterogeneous. Distribution of these characteristics are created with high consideration. These characteristics are farm size and prestige.

Ideally, I like to do more experiments by making the preference and tie strength heterogeneous as well. More importantly, I prefer to combine the experiments of different networks and heterogeneous agents. However, the number of experiments that are required to see convergence in agent-level KPIs are very high. This made experiments needed for each hypothesis very computationally expensive. Comparison between the ideal design of final sets of experiments (in which sampling is done over all different network designs and all different distributions of agent input variables) and the current design of final sets of experiments is the subject of figure 5.8.

As a result of these considerations, I decided to limit the number of hypotheses that are tested. Moreover, the experiments that are performed for understanding the network characteristics impact on the outcome are done with homogeneous agents. There are two reasons for this. First, this allows the comparison to be fully focused on the network characteristics, and secondly, this is computationally less expensive and more hypotheses can be tested. The second reason is also why the heterogeneous agents’ experiments are done using the same network as the one from the initial modeling steps. It is a simple flat network, where all agents have six connections in a very similar fashion.

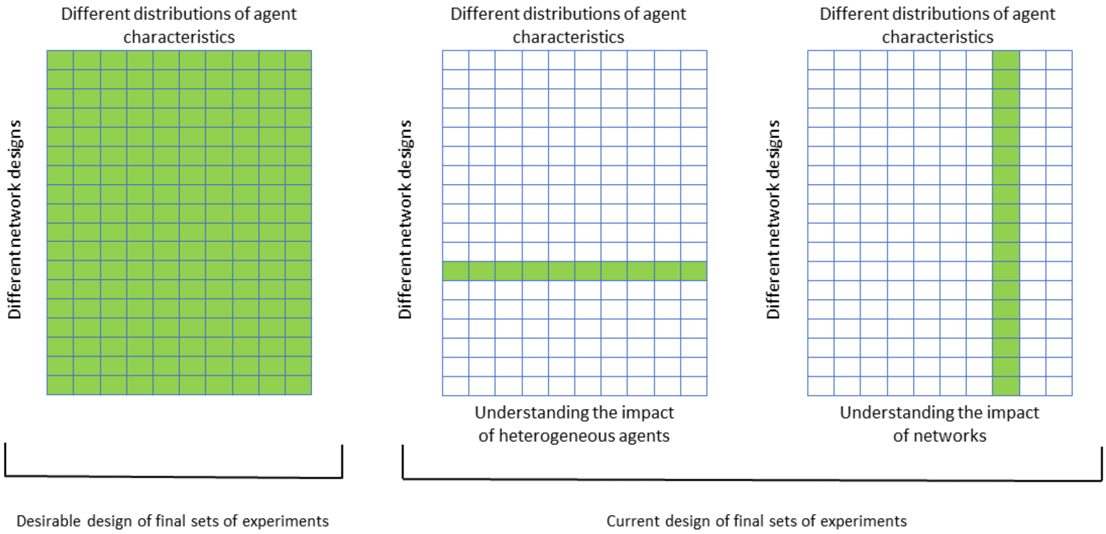


Figure 5.8: The ideal design of final sets of experiments versus current design of final sets of experiments

The focus of this study is observing the emergence of leadership and its relationship with the initiation of collective action. Nonetheless, the model allows for analysis of the potential for general agreement by reporting the final ecological pressure and the time it takes the system to reach consensus (system-level KPIs). Leadership indicators reported here are enabling and echoing leaderships (which are forms of effective leadership). They are called agent-level KPIs. The relationship between these two levels of KPIs is of interest as well. Agent-level KPIs in each model run are sets of values with as many items as the number of agents, however, only the mean of these indicators in each run is taken to the account for these experiments. They are called mean enabling leadership and mean echoing leadership. Effective leadership can be calculated based on these two and therefore it is not part of the KPIs that are analyzed.

For complete replicability of results, the random seed used in R and NetLogo for creation of the social network, the ecological network, and agent characteristics are controlled and the user of the code and the model can choose it.

5.6.1. Understanding the impacts of networks

First, some explanations are needed for the network characteristics used here. Network density refers to the number of connections in a network to the maximum possible connections (Hermans & Cunningham, 2018). There are more possibilities of reaching and influencing other actors in a dense network (Marwell, Oliver, and Prahl 1988 cited in Hermans and Cunningham 2018). Actor-level network characteristics of centrality used here are degree and betweenness. Actor centrality shows the importance or power of an actor in a social network (Hermans & Cunningham, 2018).

As described by Walsh (1994) (as cited in Hermans and Cunningham 2018) degree is the number of ties an actor has, and betweenness is the number of the shortest path between other actors that include the actor under analysis. To be able to compare results between networks of different size these values are normalized. For degree centrality normalization is done by dividing the raw centrality value by $n-1$, where n is the number of actors in the social network. To normalize betweenness centrality, the raw centrality value is divided by $(n-1) \times (n-2)/2$, which gives the maximum number of connections that could have passed through an actor in an undirected social network of n actors.

Centralization metrics should not be mistaken with the centrality of actors. Centralization metrics are showing the overall cohesion of a network (P.81) and is calculated based on the sum of differences between centrality measure of the most central actor and other actors divided by the maximum value that this some of the differences can get (Scott, 2000, P.90). For example degree centralization of a star-shaped network, where every agent is only connected to a central agent as the only actor with more than one tie, is one. If every actor is connected to all other actors (density = 1) the degree centralization will be zero.

From this discussion at least it is possible to say the density of a network is a factor to study. The population of users is another factor that is included in the SES framework and has been of interest in studies of collective action problem (Ostrom, 2009a) and common pool resource management (Agrawal, 2003).

Initial experiments for proper design of the network experiments

Some initial experiments helped with the understanding of other network measures that might be important. Also, there was a need to know the right number of replications for a convergent outcome. Figures 5.9 and 5.10 show one example of many different scenarios that were tried out.

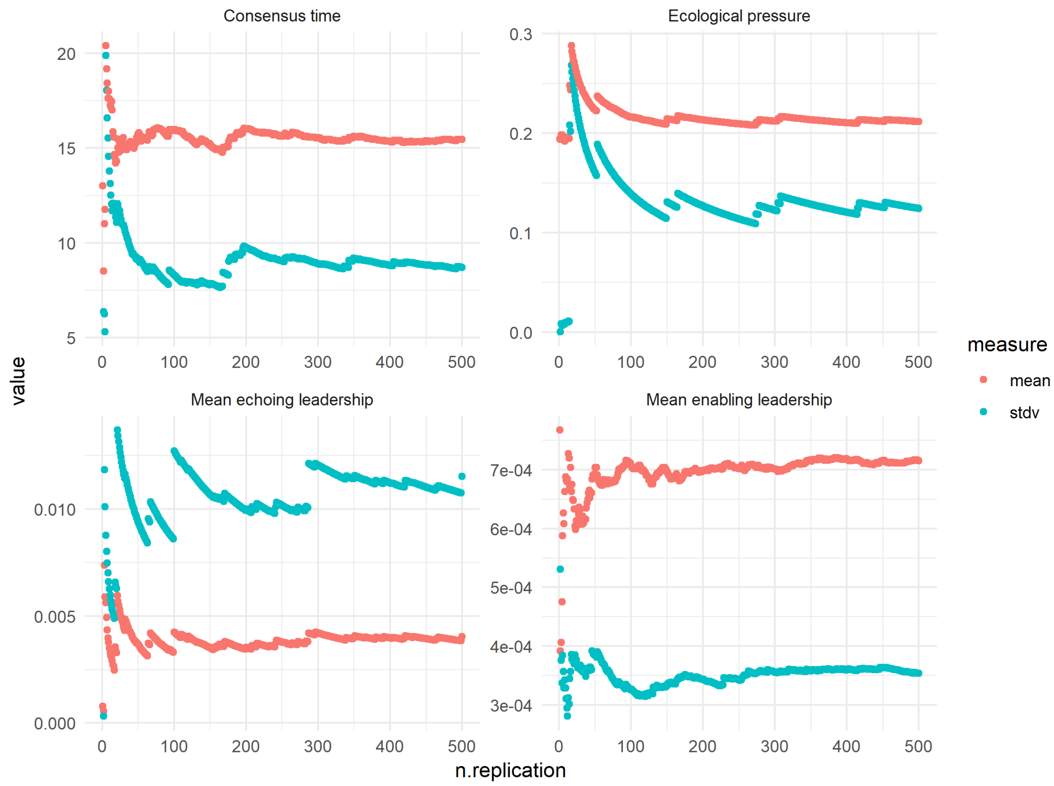


Figure 5.9: Cumulative mean and standard deviation of KPIs for 500 replications of one of the initial scenarios analyzed (population of 40 and density of 0.2)

There are many outliers as you can see. In figure 5.10, some replication reported ecological pressure of one. This is because reaching consensus was not possible and the network is *disconnected*, meaning some agents are not connected to the rest. These are not interesting for this study and are removed.

Even after removing these cases, there are still many jumps in consensus time or mean of echoing leadership, similar to those in figure 5.9. Focusing on these replications showed that many of these cases have bridging agents. Since these cases show a completely different behavior, they need a separate study. Due to time and computational constraints, I chose not to study them for now.

To understand other network measures that might be important and cause the remaining jumps in the model KPIs' cumulative mean and standard deviation plots, 2000 replication of a network with a chosen population (40) and density (0.2) was done (see figure 5.11). These networks were created to be connected and have no bridges. Removal of bridges was done based on measuring betweenness of agents and checking if each branch (agents who are completely connected) has more than one connection from other branches. To elaborate, if an actor in a network is connected to just one actor (or none) with betweenness centrality of

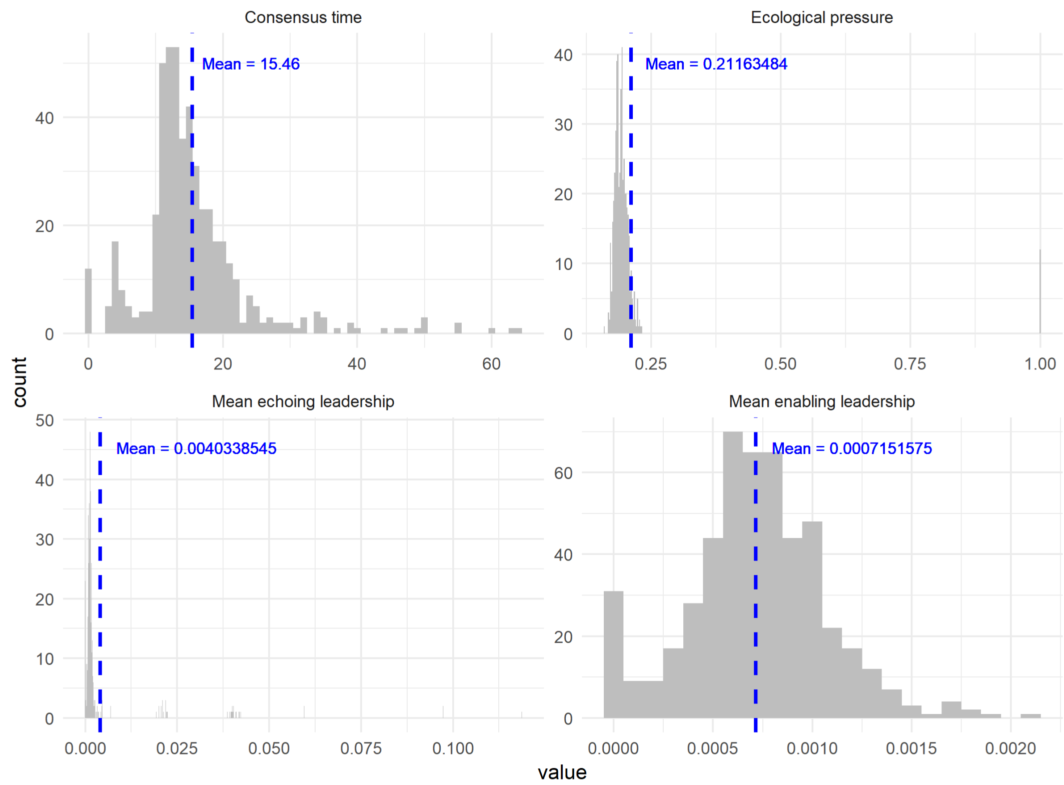


Figure 5.10: Histogram of KPIs for 500 replications of one of the initial scenarios analyzed (population of 40 and density of 0.2)

bigger than zero, that actor is either a bridge or connected to a bridge. This check can get rid of some of the networks with bridges before using them as inputs in the agent-based model. In the other case, when agents of one branch are just connected to one other agent from a different branch, the latter is a bridge. Even with these considerations, there are still some networks with bridges that are created. Those are just removed from the results.

Although in figure 5.11 the model outcome might seem to follow a normal distribution, agent-level KPIs are not normally distributed for many scenarios (for example see figure 5.12), due to the high number of scenarios in which no leadership emergence happens. By examining many of these cases, I found two reasons for this. One reason is the existence of satisfied agents which are not well-connected to dissatisfied agents. For example, there is a highly satisfied agent which is only connected through two other satisfied agents to any dissatisfied agent. This agent won't be subject of much influence and therefore high ecological pressure is needed to convince it. It was already argued that high ecological pressure, leadership emergence is less prominent. This reason relates to the idea promotion phase. If the model formalization allowed negative leadership indicators, I assume that this reason still would have led to normal distribution. The other reason, which includes most of the cases with no emergence of leadership, relates to the idea elaboration phase. In these cases, the idea creator is mostly connected to satisfied agents and hence, idea elaboration fails.

Trying to find a relationship between network measures and KPIs the figure 5.13 was insightful in the following way. At the first look, it might seem to be irrelevant, however, my hypothesis here was when degree centralization increases, the average of mean echoing leadership distribution also increases. I proved this by using the Wilcoxon signed-rank test. Plotting KPIs against the betweenness centralization did not show any easy to understand the correlation, yet, since bridges were actors with significantly higher betweenness centrality than their neighbors, Wilcoxon test was used to determine if there is a significant difference between means of KPIs in case betweenness centralization changes. For consensus time and mean echoing leadership both of these network measures showed to be important in determining the mean of the distribution ($p - value < 0.05$).

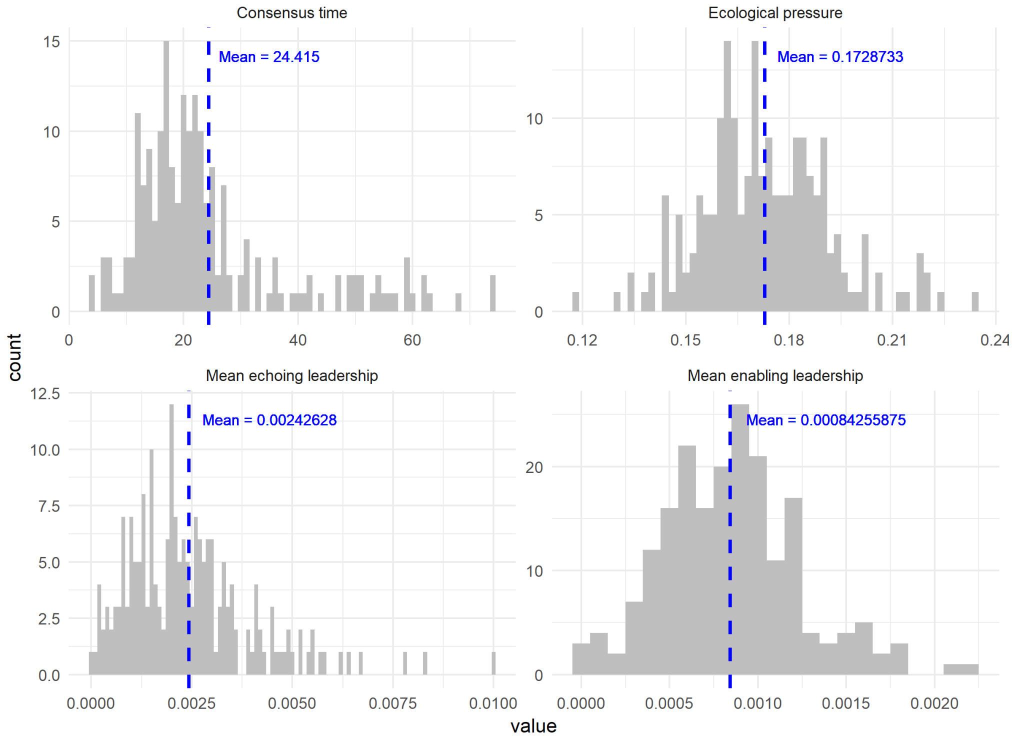


Figure 5.11: Histogram of KPIs for 2000 replications of one of the initial scenarios analyzed (population of 40, density of 0.2 and without bridging agents)

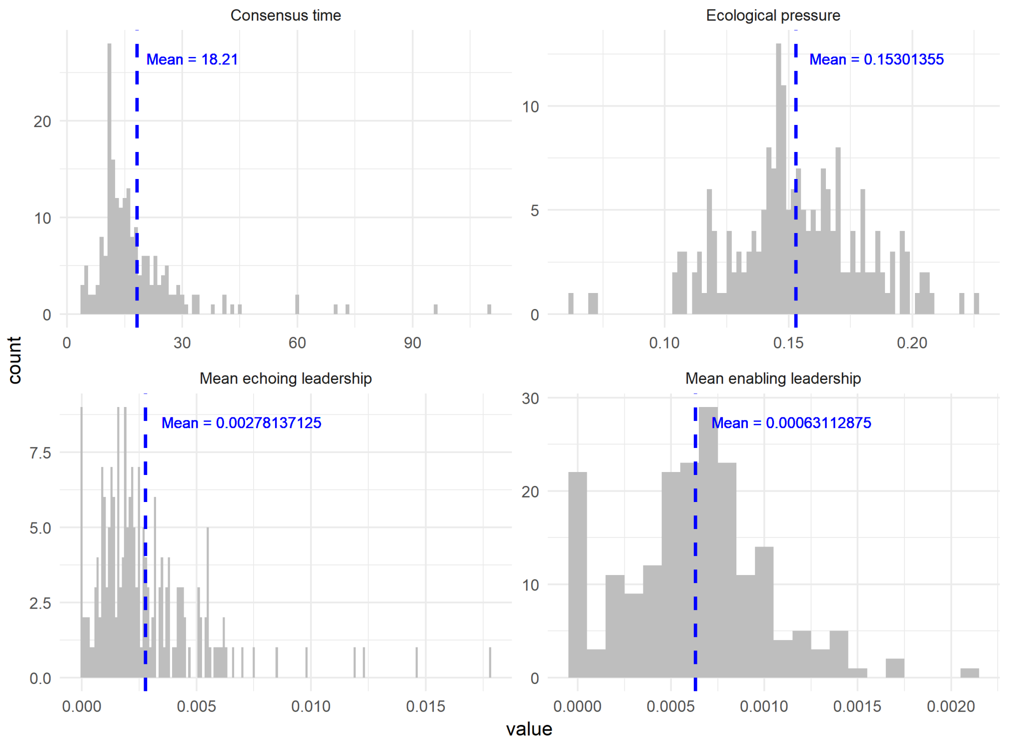


Figure 5.12: Histogram of KPIs from one of the experiments which shows outcome distribution doesn't follow a normal distribution

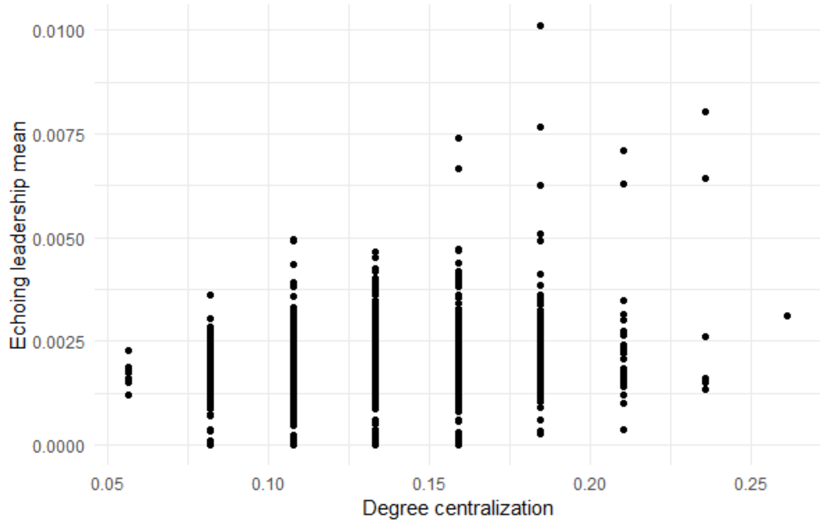


Figure 5.13: Scatter plot of mean echoing leadership indicator versus degree centralization measure

Hypotheses and the experiment design

As a result of these findings, I designed the networks with different populations, densities, betweenness centralizations, and degree centralizations for the following hypotheses that I created based on literature and initial experiments:

1. Increasing the population of agents in the system makes reaching agreement harder (in both terms of consensus time and ecological pressure), while leadership indicators increase.
2. It is easier to reach consensus in denser social networks, however, leadership indicators will decrease.
3. Higher degree and betweenness centralization contribute to a higher mean of the leadership indicators, however, reaching consensus will become more difficult.
4. There is a linear relationship between mean echoing leadership and mean enabling leadership across all these scenarios.

Table 5.2 shows the range of variables used to design the networks needed to test the correctness of these hypotheses.

Table 5.2: Network measures used in the experiments

Network measure	Low	Mid	High
Population	30	40	50
Density	$(0.14, 0.16)$	$(0.19, 0.21)$	$(0.24, 0.26)$
Degree centralization	$(0.06, 0.1)$	$(0.10, 0.14)$	$(0.14, 0.18)$
Betweenness centralization	$(0.125, 0.175)$	$(0.175, 0.225)$	$(0.225, 0.275)$

These range of variables should create 81 different scenarios, however, it was not possible to create any network with high population and density in any ranges of degree centralization and betweenness centralization used here. As a result, there are 72 different scenarios, and for every scenario 200 networks are created with these limits. Networks are created in R randomly while the random seed is controlled and saved. Each network is checked to be connected (without any isolated agents) and to be clear of any bridges. Measures which were taken did not remove all networks with bridges, but it was quite successful. Between 14400 networks that were created only 24 networks included a bridge. 19 networks also had the same network metrics, however, the ecological structure in these replications still differs. This limited number of undesirable networks are acceptable for me.

5.6.2. Understanding the impacts of heterogeneous agents

A study of farm sizes worldwide, that was done by comparing the distribution of farms grouped by their size, has shown that majority of farms are of the smallest group and as the size of farms increases their number drops, however the difference in frequency is also decreasing, therefore farm sizes resemble an exponential decay distribution (Lowder, Skoet, & Raney, 2016). The other agent characteristic, which represents a natural phenomenon of human beings is assumed to follow a log-normal distribution.

As argued by van der Zaag (1992, P. 51), access to land as a part of the physical and ecological system plays a role in limiting possible actions or providing opportunities. Similar to the study by van der Zaag (1992), in this model water rights are tied to the land access, and thus it is even more important. Komakech et al. (2012) concluded from their case study and analysis that heterogeneity of actors in different aspects can compensate their inequality, however, extreme inequality can make the actors just leave instead of participating in collective action. This is not possible in the model and hence it can be interesting to see the model behavior in cases of extreme inequality. They used the Gini coefficient to measure inequality, which I use here as well. Furthermore, Komakech et al. (2012) have observed that actors with higher endowment were more powerful and drove the direction of general meeting. In this model, I use this observation as an input for a hypothesis.

Hypotheses and the experiment design

The hypotheses that are being studied in this section are as follows:

1. System-level KPIs and Leadership indicators have a linear relationship with farm size inequality (based on Gini coefficient). In other words, inequality can make reaching consensus easier. The behavior in the real world is u-shaped because farmers with a very low endowment which may see the situation as unfair might leave the system. Leaving the system is not implemented here, therefore, a linear relationship is suggested.

2. If land access and prestige of each agent are connected, that is if farmers with bigger farms are more prestigious in the system, reaching consensus will become easier and there will be more prominent leaders.

3. Leadership indicators and the final ecological pressure have a reverse relationship. In other words, more leadership emergence should be observed when communities in a scenario can reach consensus in low ecological pressure.

Farm and prestige are assigned using gamma distribution in the setup phase of the model in NetLogo. Exponential decay is a special case of gamma distributions (when the shape is one or lower). There is no log-normal distribution in NetLogo, however, it is possible to imitate it using gamma distributions. Farm distribution is changed in different experiments based on what is required by the hypotheses, yet, its average is taken to be the same as the base value that was used in previous modeling steps so that comparison is focused on differences in distribution shape and not the mean value.

I needed to implement three changes to make agents characteristics of farm and prestige heterogeneous. For both of them, I use the gamma distribution. For prestige, the shape parameter is 6 and the rate parameter is 4, which will have the same mean as the constant that was used in previous experiments (0.25). For farm distribution, a decay shaped distribution was needed. So the shape parameter is 1 or below. To create three different endowment inequality of low, mid and high, I use three different shape parameter of 1, 0.6 and 0.35 respectively. Rate parameters of these distributions are 20, 12 and 7, so that the mean of these distributions are 0.05. The farm distribution is then added by 0.2 to make the mean farm size of agents in this set of experiments the same as the previous experiments (0.25). The Gini coefficient for the chosen distribution will be 0.14, 0.12 and 0.1 (approximation based on 10000000 random number from gamma distribution). Of course, all of these variables are still limited between 0 and 1. The last change relates to the connection between prestige and farm. To make them connected in half of the implemented scenarios for this subsection, the prestige of each farmer is set to the same value as the farm. In total 6 different scenarios were needed to test the formed hypotheses.

The number of replications needed for this section is very high. Each scenario needs 1600 replications to show convergence in agent-level KPIs. Similar to the previous subsection, model outcomes are not normally distributed because of the high number of replications in which no effective leadership (and consequently no enabling or echoing leadership) emergence occurs. Therefore, to compare KPIs at different scenarios, the Wilcoxon test is used (available in appendix C). In these experiments, the lack of leadership emergence is due to the formalization of potential dissatisfaction. Potential dissatisfaction is modeled using a threshold (potential dissatisfaction limit), so, a very satisfied agent might become suddenly dissatisfied. In these situations, much of the needed influencing that was needed to convince this satisfied agent becomes unimportant. Many agents are dissatisfied and influencing each other, therefore, none of them are absolutely necessary to reach consensus at the same ecological pressure. This results in no emergence of leadership. I consider this a limitation of the model. The results of the final two sets of experiments are in the next chapter.

6
Results

I designed two sets of final experiments at the end of chapter 5. I implemented these experiments using R (to create the input variables), and NetLogo (to run the simulations). I analyzed the outcome of these simulations in R. Moreover, whenever needed I focused on specific replications to understand the dynamics so that I will have high confidence in explaining the outcomes.

The mean enabling leadership and the mean echoing leadership represent the overall emergence of echoing leadership and enabling leadership in one replication. The presented KPIs are average over all replications of a scenario. So, for example, average of the mean echoing leadership is the mean of echoing leadership per replication averaged over all replications of a scenario. The final ecological pressure is the necessary pressure for the community to reach consensus. Therefore, a higher final ecological pressure means the community had a low potential for reaching an agreement. The consensus time only shows how fast the idea can propagate inside a community.

Higher values for leadership indicators are desirable, while, for the system-level KPIs of the final ecological pressure and the consensus time, lower values are more desirable. In the graphs of this chapter, the desirable values are green, while, the undesirable ones are red.

6.1. Understanding impacts of networks

Model outcomes using the networks that I designed according to the description in chapter 5 as input resulted in mostly convergent results, nevertheless, Wilcoxon test is used to make sure the conclusions that are made based on these outcomes are from KPI distributions with significantly different mean values ($p - value < 0.05$). Appendix B can provide more information on this and includes the figures that show the results of the Wilcoxon test.

Figures 6.1 to 6.4 show the results of these experiments. I present these results using heatmaps. On the Y-axis, one can see the population and the density. On the X-axis, degree centralization and betweenness centralization measures differentiate distinct scenarios. The choice of outer factors are arbitrary and they are consistent over all the figures. In some cases, the change of population is more significant than the change of density in determining the change in KPIs and in some other cases opposite pattern can be seen. That is why I call these choices arbitrary.

From figure 6.1 two important observations can be made easily. As the population or density increases, the average of the ecological pressure necessary for reaching consensus becomes less.

Considering degree centralization measure, the results would be somewhat contradictory. For example, it is possible to say with confidence that in high population and high density, by decreasing the degree centralization, the average of the final ecological pressure decreases as well, while, the opposite sign can be seen from the high population, low density. Betweenness centralization seems to have an inverse relation with the average of the final ecological pressure in most cases, however, there are exceptions to this rule, like in mid population,

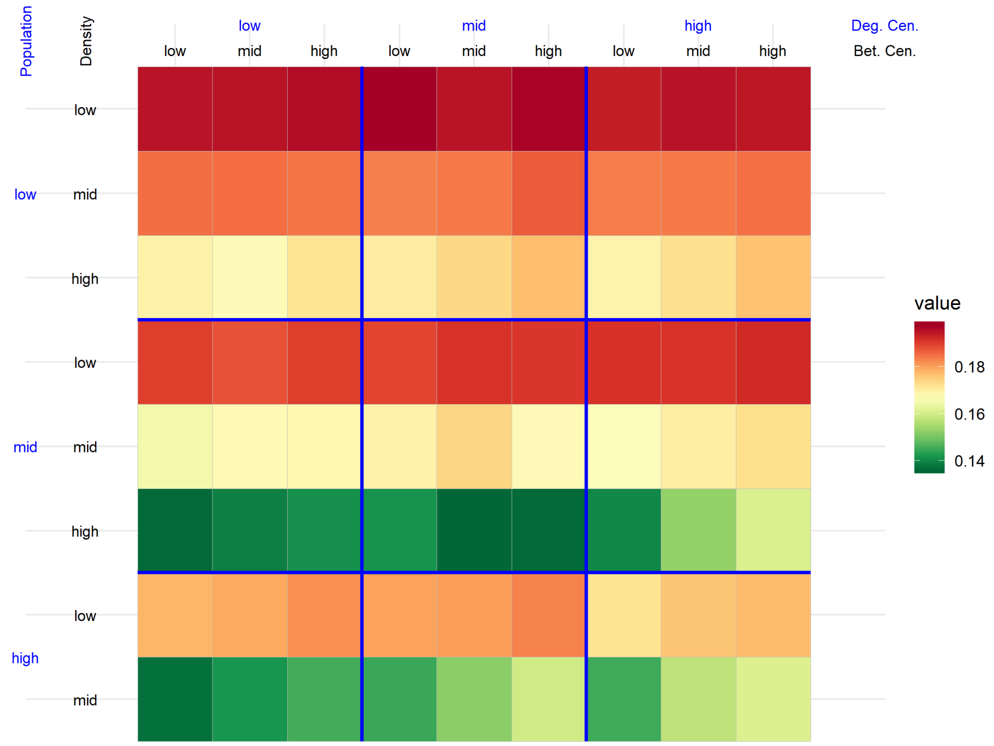


Figure 6.1: Heatmap representing average of final ecological pressure in different scenarios with different network characteristics

mid density and mid degree centralization. Very interesting to observe both of these contradicting patterns in mid population and high density experiments. It seems there is non-linear behavior. However, the exceptions mentioned cannot be explained alone with these network measures. It might be because of some other network measures that are not taken into account in these experiments.

Based on figure 6.2, opposite behavior can be seen from consensus time regarding population and density. Higher population or density increases the average of the consensus time. Again centralization network measures seem to have a non-linear behavior. At lower population and density, lower centralization results in a low average of the consensus time, while as population and density increases, lower centralization leads to a higher average of the consensus time.

Average of mean enabling leadership, as presented in figure 6.3, decreases as communities have more people or at higher degree centralization in the social network. There is one exception in which, the average of the mean enabling leadership increases at higher degree centralization. Other apparent exceptions have a p-value of higher than 0.05 from the Wilcoxon test.

Mean enabling leadership has a more complicated nonlinear relationship with density and betweenness centralization measure. In lower population increasing density at the same centralization measures increases enabling leadership, however, at the high population, this is opposite.

For betweenness centralization, in some cases, it is possible to see that mean enabling leadership is higher at some of low betweenness centralization scenarios (while other factors are the same), while at some of the other low centralization scenarios, the average of the mean enabling leadership becomes lower. It is difficult to see a general pattern between the average of the mean enabling leadership and the betweenness centralization, however, there is a possibility of optimum point by combining betweenness and degree centralization measures. For example, at the low population, high density, low degree centralization, and mid betweenness centralization, the highest average of the mean enabling leadership can be

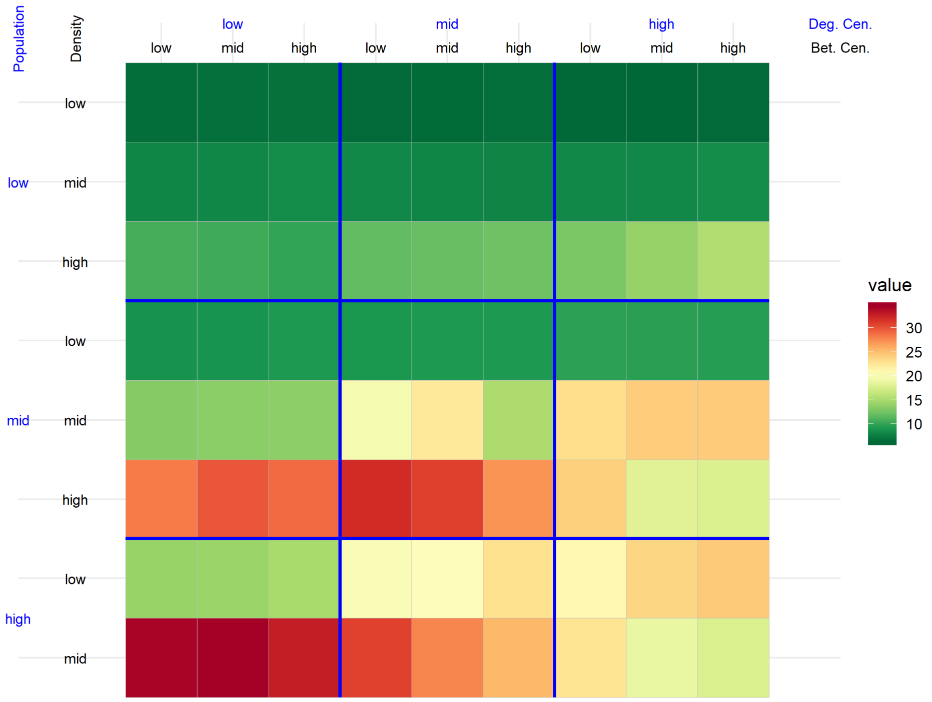


Figure 6.2: Heatmap representing average of consensus time in different scenarios with different network characteristics

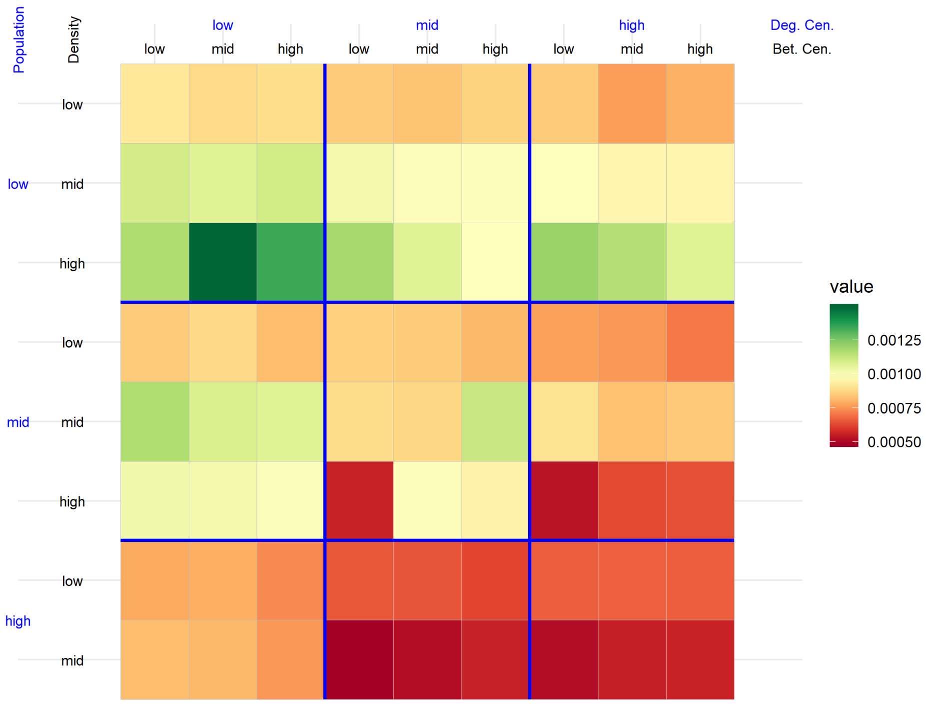


Figure 6.3: Heatmap representing average of mean enabling leadership in different scenarios with different network characteristics

observed.

Considering figures 6.1, 6.2 and 6.3 there is no sign that the average of the mean enabling leadership has any obvious correlation with consensus time or the required ecological pressure for reaching consensus.

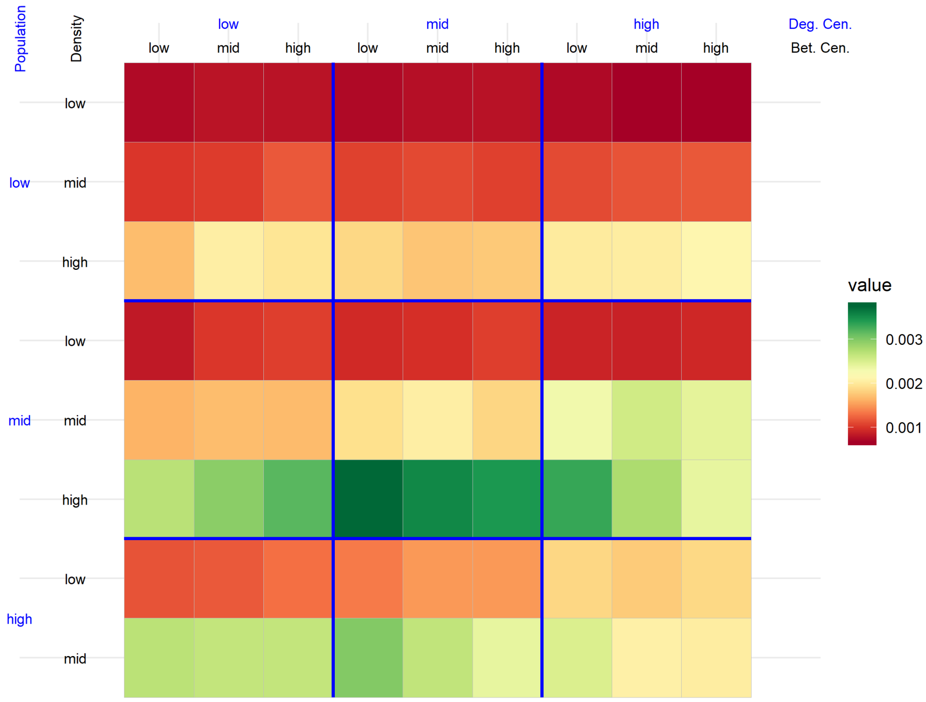


Figure 6.4: Heatmap representing average of mean echoing leadership in different scenarios with different network characteristics

Contrary to final ecological pressure, the average of the mean echoing leadership (see figure 6.4) increases at higher populations or higher densities. Centralization measures' impact on the average of the mean echoing leadership depends on the population and density. Considering different horizontal lines, sometimes, mean echoing leadership increases at higher degree centralization and sometimes it decreases. Effect of betweenness centralization on mean echoing leadership depends on degree centralization. At low degree centralization, higher betweenness centralization means more prominent emergence of echoing leadership. On the other hand, at mid and high degree centralization opposite behavior emerges. The combination of centralization measures seems to show "n" shaped effect on the average of the mean echoing leadership.

Mid population and high density is the most interesting case here. It shows reaching maximum at a certain combination of centralization measures and going down again.

Further analysis didn't provide any proof for the correlation between mean enabling leadership and mean echoing leadership. However, there seems to be a linear relationship between the average of the mean echoing leadership, the average of the consensus time and the average of the final ecological pressure (see figures 6.5 and 6.6).

All hypotheses of this set of experiments are rejected. It is not possible to give any simple rule about the impact of centralization measures on system-level or agent-level KPIs. Consensus time and mean echoing leadership increases at higher population and density while final ecological pressure increases. For enabling leadership, it is possible to say there is less prominent emergence of leadership in case population increases. Moreover, based on significant observed differences in various scenarios, enabling leadership emergence is most prominent in lowest degree centralization.

Another interesting pattern that I observed is that recorded echoing leadership values are higher. Hence, it might as well happen that in communities there is more need for echoing leaders than enabling leaders. This need depends on the structure of the social network.

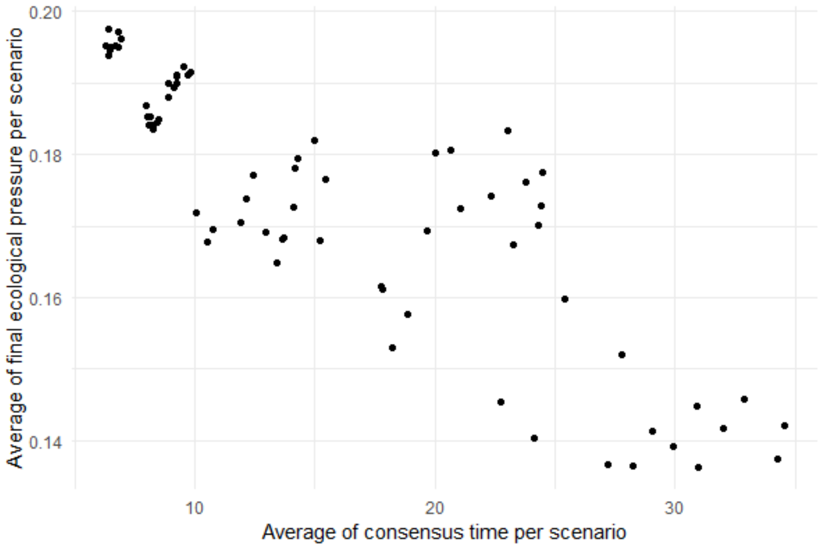


Figure 6.5: Scatter plot of average of final ecological pressure per scenario versus average of consensus time per scenario

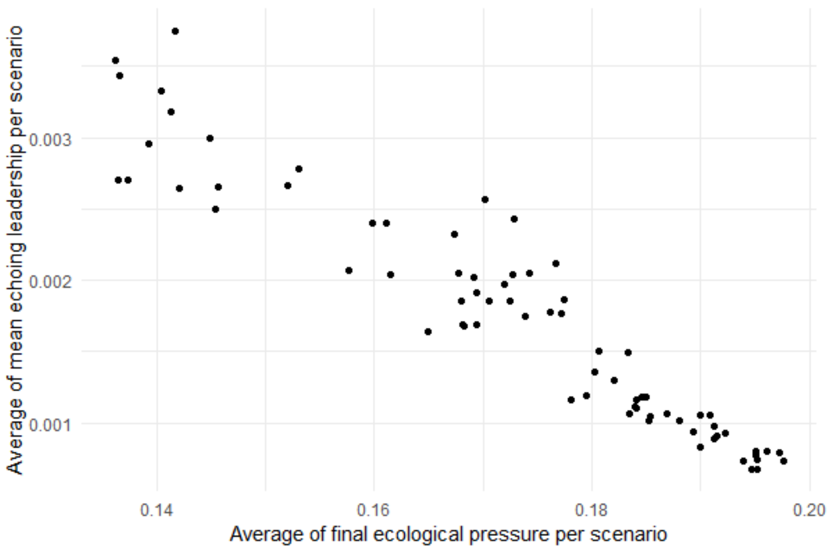


Figure 6.6: Scatter plot of average of final ecological pressure per scenario versus average of mean echoing leadership per scenario

Explaining the emergent results

To explain the relationship between the final ecological pressure, the consensus time and the mean echoing leadership, my reasoning, based on what I learned from initial experiments with the model, is that higher emergence of echoing leadership and consensus time is due to lower final ecological pressure. At these conditions, agents have a lower dedication and thus, their influence is weaker. This calls for more support and feedback from each other for dedications of agents to rise enough to convince all non-dedicated agents. At the same time, every dedicated agent is more indispensable and therefore they have higher echoing leadership, which is the bigger part of effective leadership. This pattern is repeated in preliminary experiments and the other set of final experiments

To explain why final ecological pressure decreases at higher population and density, I must propose a hypothesis. My hypothesis is that, this behavior is due to the average number of connections per agent. By increasing density, this number increases, besides, when population increases at the same density, the average connection per agent increases as well.

For example, 10 agents with a density of 0.5 will have 4.5 connections on average, while 5 agents with the same density only have 2 connections on average. When the number of connections is higher, it is easier for an idea to propagate. To elaborate, when agents affect each other the increase in the dedication of the subject is only a small ratio of the influencer, which may be insignificant alone, but if there is a higher number of connections per agent, this change in dedication per step is more significant. If this hypothesis proves to be true, it will be very interesting to see how model behavior changes by increasing the population at the same average connections per agent.

To check these new hypotheses, I reordered the Y-axis of results based on average connection per agent. These reordered heatmaps are figures 6.7, 6.8 and 6.9.

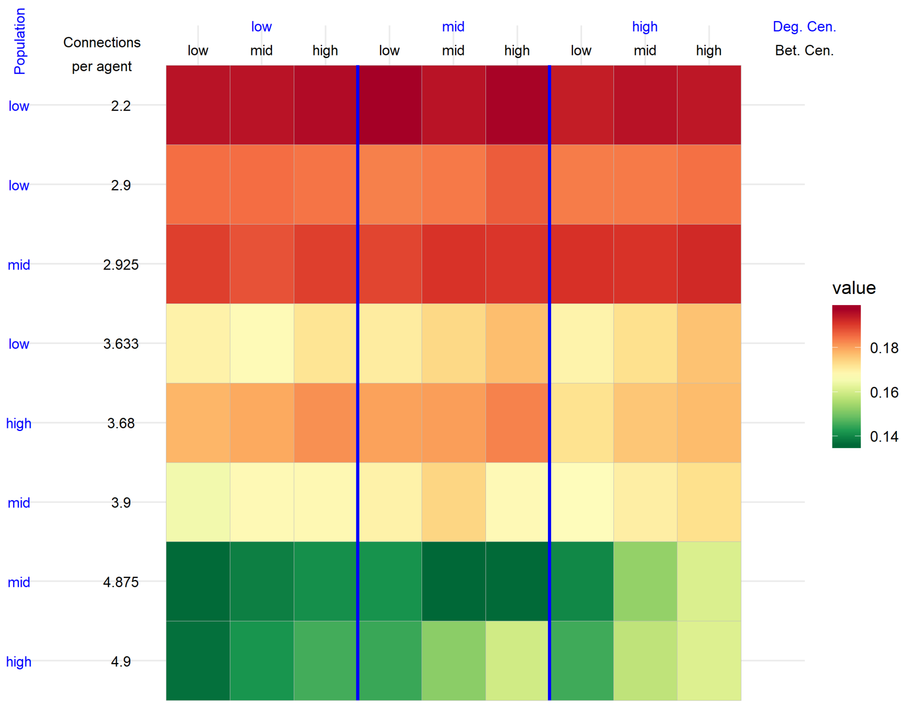


Figure 6.7: Heatmap representing average of final ecological pressure in different scenarios, reordered based on average connection per agent

As you can see, these results support my new hypotheses, still, it seems the average connections per agent is not the only important factor. For example, in figure 6.7, at 3.675 connections per agent, a break in a decreasing trend is apparent. Other network characteristics, such as population, might still be an important factor in determining the system behavior. I specifically named population because most of the breaks in trends relate to a horizontal line which is surrounded with horizontal lines of different populations.

Change in the emergence of enabling leadership cannot be easily explained by the average number of connections. Unlike the echoing leadership, the enabling leadership doesn't show a direct relationship with the final ecological pressure in these experiments.

My hypothesis for this behavior is that a combination of final ecological pressure and average connections per agent determine enabling leadership emergence. That is the higher number of connections per agent lessens the importance vision promoted by one agent (therefore, there is less need for enabling leaders in comparison to echoing leaders), however, lower final ecological pressure increases the importance of vision advocated by one agent. Unlike the previous hypothesis which I have high certainty in its correctness, I have low confidence in this hypothesis. I didn't find any interesting pattern from reordering the Y-axis of figure 6.3 based on the average connections per agent.

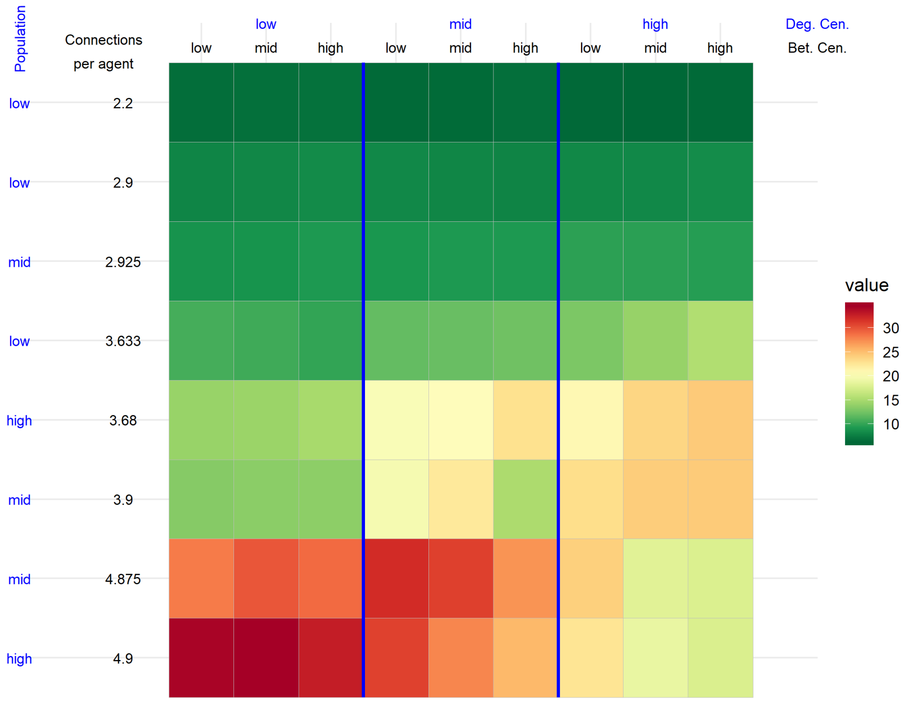


Figure 6.8: Heatmap representing average of consensus time in different scenarios, reordered based on average connection per agent

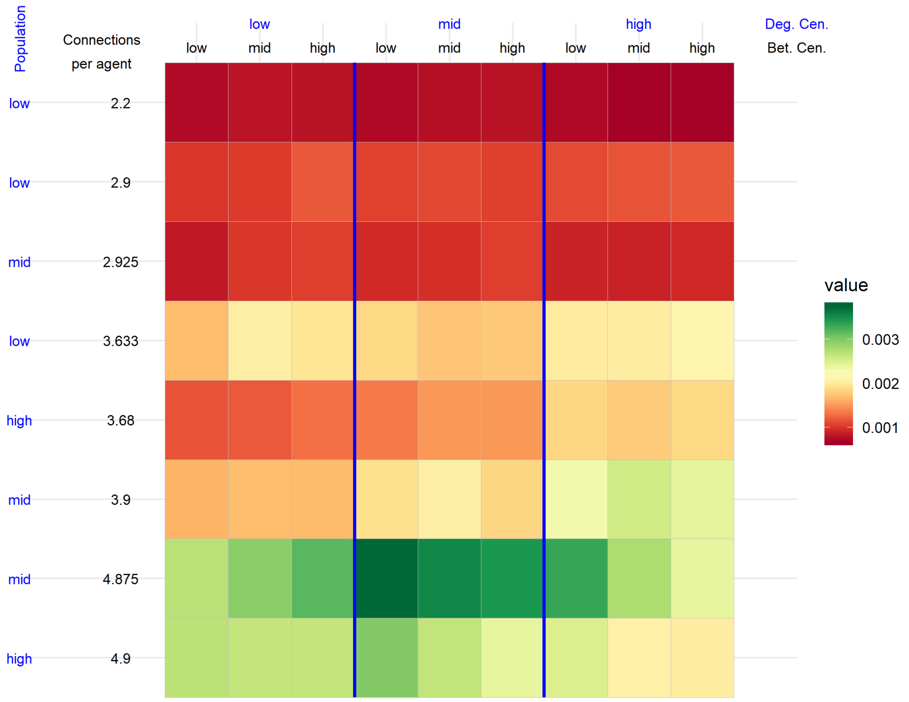


Figure 6.9: Heatmap representing average of mean echoing leadership in different scenarios, reordered based on average connection per agent

6.2. Understanding the impact of heterogeneous agents

The results of these experiments are presented in figures 6.10 to 6.13. In these figures, on the X-axis, the inequality of farm sizes in scenarios is specified. For example, low inequality means the farm sizes for the replications of this scenario are chosen from a distribution that results in low inequality as reported in chapter 5. On the Y-axis, connection between farm and prestige is shown. For those scenarios, which this is true, the prestige of farmers is based on their farm size.

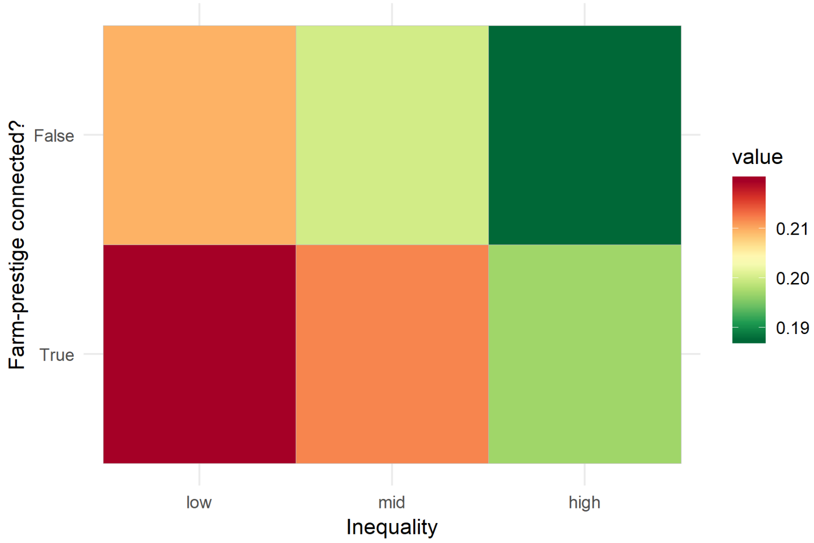


Figure 6.10: Heatmap representing average of final ecological pressure in different scenarios with random agent input variables

Given the assumption used in the model, the average of the final ecological pressure is lower when inequality increases. It is important to note the inequality used here might be much lower than what happens in real life and it was not possible to cover a wide range of inequalities here. For example, Komakech et al. (2012) reported a Gini factor of 0.58 in their study. In the range of inequality used for this experiments, it is possible to observe higher inequality enables a community to reach consensus at lower ecological pressures. The other axis of the experiment provides information on how the system behavior would change if people with bigger endowment are considered more prestigious in a community. In these communities, the final ecological pressure will be slightly higher than their counterpart with the same inequality.

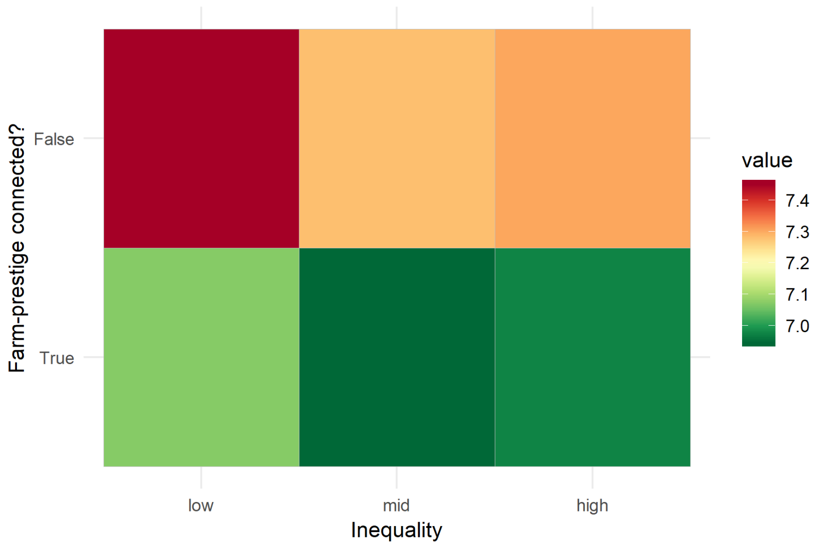


Figure 6.11: Heatmap representing average of consensus time in different scenarios with random agent input variables

Despite the high number of replications, it is not possible to compare the consensus time of experiments with different inequalities. The only reliable observation that can be made is that in communities where people's prestige depend on their endowment, consensus time is slightly lower than communities where prestige and endowment are not related to each other. Comparing to the range of consensus time that was possible by changing network characteristics (figure 6.2), these changes (figure 6.11) are negligible.

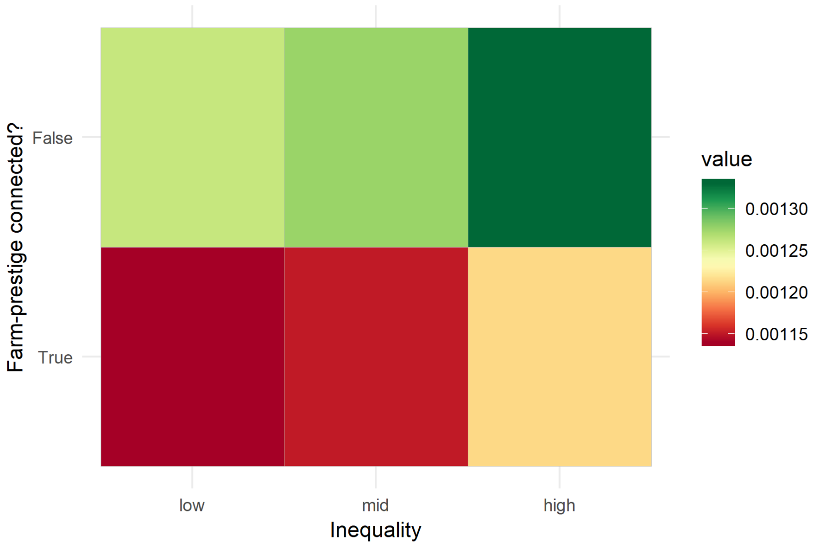


Figure 6.12: Heatmap representing average of mean enabling leadership in different scenarios with random agent input variables

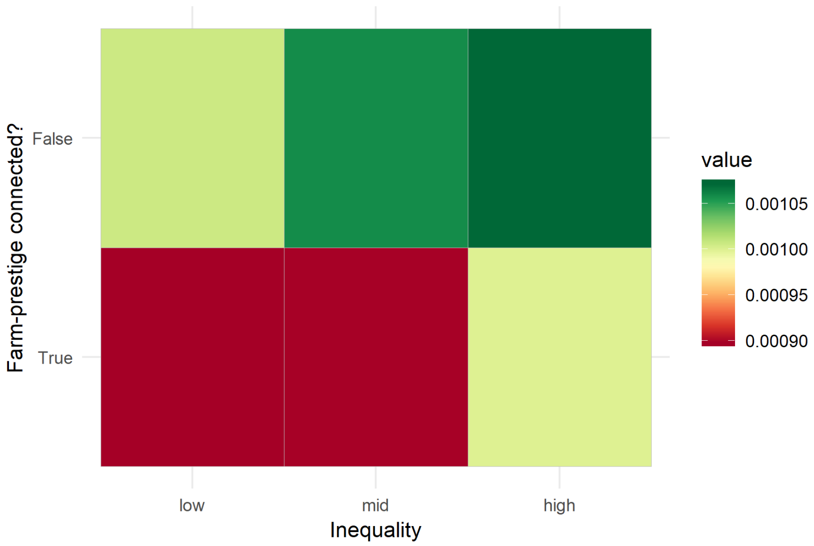


Figure 6.13: Heatmap representing average of mean echoing leadership in different scenarios with random agent input variables

The average of the mean enabling leadership (figure 6.12) and the average of the mean echoing leadership (figure 6.13) are showing opposite behavior (but similar in being desirable) to the average of the final ecological pressure. Higher inequality causes more prominent emergence of enabling and echoing leaderships while these leadership indicators will decrease if farmers' prestige depends on their endowment.

Between the hypotheses that were suggested only the second one proved to be wrong and others are accepted, however, this is limited by the low number of scenarios. The observed behavior is opposite to the second hypothesis, that is, the final ecological pressure increases if prestige is connected to farm size of agents while mean enabling leadership and mean echoing leadership decreases.

Explaining the emergent results

Now that the social network is staying the same, when final ecological pressure is low, the emergence of enabling leadership and echoing leadership is more prominent.

Although agents with big farms might be dissatisfied because they are not using their endowment to the fullest, most dissatisfied agents are those who have not enough water for their minimum livelihood.

In higher inequality cases, agents with higher endowment are more dissatisfied comparing to lower inequality cases. Therefore, they support and promote the idea for change more actively, hence, the final ecological pressure is lower. However, they are not the most dissatisfied, and consequently, they are not the most dedicated agents who contribute the most to reaching consensus. As a result, if prestige depends on endowment size, those most dedicated agents who have small farms become less effective and the ecological pressure necessary for reaching consensus becomes higher.

7 Discussion and conclusion

I started this research by recognizing the grand challenge of having adequate access to water resources around the world in current times and future. Community-based management of common-pool water resources, as a form of collective action in communities, is a promising way to overcome this problem. Many factors are important in determining the fate of community-based governance of resources. One of them, which is crucial in the initiation of collective action, is leadership.

In this research, I studied the emergence of leadership in the initiation of collective action in communities in different steps, namely, literature review, developing a theory of leadership, case study, applying the SES framework and modeling. These different steps each had their own added value. For example, the modeling phase helped me recognize the existence of echoing leaders. I call the theory that I developed by synthesizing available studies and using findings of the model, Leadership for Community Development (LCD). This theory is the core of this research.

Leadership for Community Development is focused on communities where collective choice institutions give equal decision-making rights over changing the operational institutions and there is no authoritative control over the domain of collective action based on operational institutions. For example, in a community that community members want to change the water management system, this theory is applicable if it is only possible to change the water management system by everyone's agreement and there shouldn't be any individual or group which can dictate how the current system should be managed.

As argued in chapter 1, I believe it is possible to apply theories and knowledge between different domains of collective action in communities if crucial institutions are similar. So, as long as the aforementioned institutions are similar, LCD can be applied to different subjects of initiating collective action (like community-based management of resources or grassroots innovations). That is why what started as a study on leadership in community-based management of common-pool resources evolved to become more focused on community development. The name of this study, *emergence of leadership in communities*, is chosen for the same reason. Community leadership, as emphasized in chapter 1, has not gotten the attention it deserves. This is while collective actions in communities, in which leadership is significantly important, can solve problems beyond overuse of common resources, like grassroots innovation projects.

In this chapter, I intend to provide a complete picture of leadership for Community Development by answering the research questions using outcomes of different steps. I will point out the academic relevance and my contributions more directly. Moreover, I will discuss the implications of the findings of this study for supporting collective action in communities. In the end, I will discuss the limitations of this research and my recommendations for future work.

7.1. Answers to the research questions

The answers to the research questions in combination with each other can provide a complete picture of this research and its findings. The process was not linear for me and I won't linearly answer them either. I will use the findings of different steps to give a comprehensive and integrated answer and I will explain the consequences of each answer for other steps.

Sub-question 1 - How can the leadership be identified in the context of initiating collective action in communities?

To identify leaders, I needed to specify the theoretical lens, the perspective or the area of focus. By synthesizing over different perspectives of leadership in communities, I decided to find leaders by looking at decisions that lead to the final outcome. If I chose a different lens, for example choosing network metrics and position as the perspective of leadership for this study, then the definition of leadership could have been a network measure like degree centrality. This choice was in line with the chosen core institutions.

Based on this perspective, I adopted the definition of leadership as influencing interactions of different actors. This definition of leadership means every actor has the potential to exhibit the emergence of leadership. Leadership itself is an emergent property of the system. I call this process emergence because people who were not considered leaders become known as leaders and if they are successful, this process leads to collective action and self-organization of the community.

The concept of leadership is used extensively in different contexts, namely, organizations, politics, civil movements, etc. It is also used in different meanings as well, like a manager or entrepreneur. In this study, from the beginning, I tried to distinguish between these different usages and to clarify what is meant by leadership. To express it as simple as possible, leadership is taken to be efforts taken to guide a community toward a common vision. These efforts that are taken to influence other community members are subject to an influencing power that depends on prestige, the content of the message (vision), the interdependence of influencer and the subject, the strength of their connection, etc. The basis for the influencing interaction is communication through the social network.

The choices of identification approach and the definition had several implications for other steps. Consequently, leadership is shown by individuals and it is not binary. Different actors might show different levels of leadership in the initiation of collective action in communities. It is very important to consider the social network and its role in different steps. The role and emergence of leaders should be conceptualized based on influencing interactions. Moreover, it is possible to structure these choices using the SES framework next to other relevant factors of social-ecological systems. In the modeling phase, the emergence of leadership should only happen through influencing interactions as well. The implication of the decision approach for the modeling phase is that the emergence of leadership should be conceptualized based on the impact of interactions on the final outcome.

Sub-question 2 - What is the role of leaders in the initiation of collective action in communities?

Synthesizing over available studies helped me to recognize the role of leaders in the initiation of collective action to be gathering the necessary material, intellectual and political capital as the requirements of starting collective action.

Leadership is an emergent property of the system through the process of innovation. This process of innovation, which is the core of leadership theory in this research, includes four phases of idea generation, idea elaboration, idea promotion (or championship) and adoption (or implementation) of the idea. Leadership is most prominent in the idea promotion phase. Management is an important part of the idea adaptation phase. Even before starting the innovation process, there might be leaders who challenge the current situation and increase the desire for change. In chapter 2, I decided to call those, who challenge the current state, problematizing leaders instead of enabling leaders as they were called in the literature. This is because enabling leaders are already a core part of the innovation process and the people who problematize and enable the community can be different and they emerge in different stages of initiating collective action.

From the literature review, enabling leaders were identified as the core leaders of a community that push the innovative change. They are the people with the vision and persistence that trigger the community and provide the common goal to strive for. Behind this vision, there is a motivation for change. It can be dissatisfaction with the current situation or a dream of a more desirable future.

All community members are influencing each other, however, not every act of influencing or leadership can be seen as effective. This was the insight that was added in the modeling phase. The model helped me understand that the influence of every agent is not effective and indispensable. This also led to the development of effective and echoing leadership concepts. So while I developed the previous concepts by synthesizing the available studies, effective leadership and echoing leadership are new concepts that I added in this research.

Effective leadership is the necessary influencing of community members for a successful idea promotion phase that leads to idea adaptation phase (conceptualized as consensus in the model). In other words, effective leadership is the indispensable influences of individuals for starting idea adoption. To find effective leadership of an individual, one needs to find how the possibility of reaching consensus would be if that individual was neutral and did not influence any community member. This means those who talk to many people or are very loud and at the center of attention are not necessarily the most effective ones. An actor at a critical point in the social network can be a very more effective leader.

Based on the roots of why actors are influencing and advocating change, the effective leadership is considered to be either enabling leadership or echoing leadership. To put it simply, consider effective leadership the aggregation of enabling leadership and echoing leadership. Enabling leadership is the main source of vision and persistence. This is an inside drive for change. While echoing leadership is the necessary influencing of some community members (like a bridge in a social network) to make this vision reach every community member as a shared a goal. Echoing leadership is due to the dedication of individuals that come from influences and persuasion of other actors. In chapter 2, it was vaguely suggested that enabling leaders might use the influencing power of other actors to promote their idea. Based on this conceptualization, this is an act of echoing leadership. Another example of a potential echoing leader is an actor who is acting as a bridge between two different subgroups in a social network.

In short, actors influence each other to convince others and direct them toward a vision. This is leadership. Not every actor's influencing is indispensable. The influencing effort which was necessary for reaching an agreement and starting the idea adaptation phase (the final outcome) is effective leadership. If this effective leadership comes from an inside desire for a change it is called enabling leadership. If this effective leadership is because other actors convinced the influencer in question to promote the idea, it is called echoing leadership.

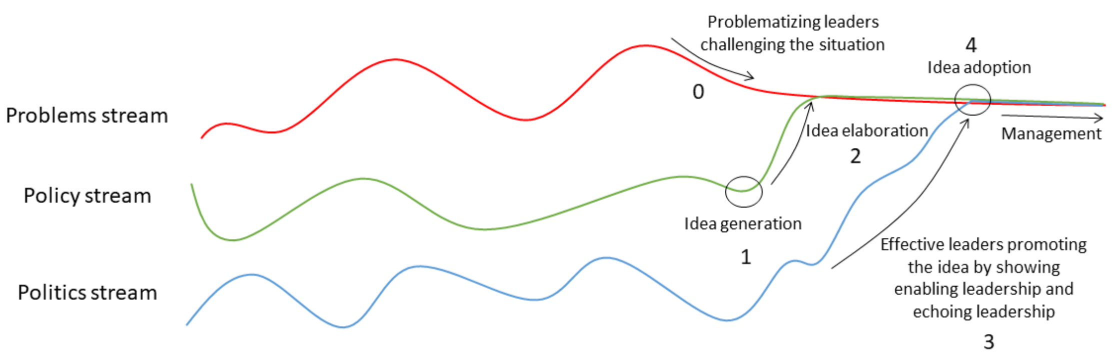


Figure 7.1: Multiple streams model representation of leadership for community development

With the help of multiple streams model (see figure 7.1), I will explain the LCD theory based on these concepts. The process can start by some actors who are challenging the current state and show problematizing leadership (0). This may lead to idea generation by an actor (1).

This actor will seek support from his or her close connections and will elaborate idea (2). In the next phase, dedicated individuals will promote the idea and show enabling leadership and echoing leadership (3). If different requirements for adaptation of idea is reached (presented by the politics stream), the idea is adopted (4). Afterward, it is the domain of management instead of leadership.

Sub-question 3 - Is it possible to observe the described role of leaders in the initiation of collective action in the case study?

To answer this research question, I studied available literature on the case and interviewed a local water management expert. From the combination of these sources, I concluded that it is possible to observe the existence of idea promotion and idea adoption phases. Moreover, considering that the idea that the leaders in Mojen promoted was very detailed and fit properly to their problem, I deduced there was an idea elaboration phase before idea promotion.

These results supported the LCD conceptualization of the emergence of leadership in communities. An important lesson from the interview for me was that the interviewee spoke about the importance of having a facilitator or facilitating leader in collective action problems in communities which can also be from outside the community. The description for the facilitator was similar to the enabling leader in this research. Lastly, this case was a source of inspiration for me on how to model dissatisfaction or the drive for change.

Sub-question 4 - Which characteristics of a social-ecological system are relevant to the impact of leaders in initiating collective action in communities?

Many factors were already identified in the process of answering the second sub-question. I used the SES framework to structure these factors. Moreover, I used the case study of this research to give an example of a comprehensive list of factors that are relevant to the emergence of leadership in the initiation of collective action in communities based on the SES framework. This is presented in chapter 4. I positioned the institutional requirements for using LCD as well as the core interactions of leadership in the SES framework as well.

An important added value of this study happened in this chapter. To use the SES framework for understanding the emergence of leadership and the role of leaders in communities, I suggested some improvements. I argued that the SES framework lacks proper differentiation between key individuals, entrepreneurship, leadership, and management. Moreover, not only social capital but also intellectual capital, political capital and material capital may be needed for collective action in the context of a social-ecological system.

Last, but most important addition, was my suggestion on separating the social network of a community from the social capital in this framework because the social network is a very important factor that requires more attention. Other researches, as stated in chapter 2, also insisted on the importance of the social network.

The results of this step were important for me to decide which factors, institutions and interactions I must include in the modeling phase. Some institutions are implemented (collective choice institution and operational institutions on using the resource), while some institutions are implicit in the model (the new idea can be a new operational institution). Moreover, the structured list of relevant factors and attributes are useful in applying the findings and insights of this research.

Sub-question 5 - What model formalization can adequately represent the emergence of leadership in the context of the initiation of collective action in communities?

This step was particularly important for me because it worked as a proof of concept that the LCD theory can explain the emergence of leadership in the initiation of collective action in communities.

Among many factors that seemed as relevant, I only used a handful of them due to limited time and scope of the study. Moreover, to get useful insights complexity should be built in steps. Water resource was limited to one type which doesn't have any temporal distribution. The implemented collective choice institution requires consensus. Operational rules in place were very simplified.

The idea that is developed in the innovation process, which can be a new operational institution, has no detail. Only one idea is possible in the model at each time. The focus is only on the innovation process and what happens before, like the role of problematizing leaders, is not implemented. This was a choice of the scope which I explained at the end of chapter 2. Moreover, the innovation process itself is modeled until the adoption of the idea. After that is in the domain of management which is not part of this research.

I assumed there is enough social capital. I only explicitly included political capital from different necessary types of capital as the dedication of agents to the idea. I did not implement networking interaction or conflict happens among the agents. The model is inspired by the case, however, it is not replicating the emergence of the new management system in Mojen and there is no data validation. Agents can create an idea and there are only two interactions between them, namely, influencing and voting for the elaboration of ideas, which are communication means that happen through the social network.

The model is very abstract and it is created to gain more insights on the emergence of leadership in communities and to provide a tool and a stepping stone for future research. With all these simplifications of the LCD theory, it was still possible to see the emergence of leadership and effective leadership (including its parts, the enabling leadership, and the echoing leadership) in innovation processes started to solve a community problem. Observing the emergence of leadership from the model that I created based on the LCD theory in combination with the lessons that I learned from the case study support the LCD theory.

Sub-question 6 - What are the most significant characteristics of a social-ecological system in the emergence of leadership in the context of initiating collective action in communities based on the model outcomes?

I discuss three sets of experiments here. They are preliminary experiments (that were mostly used for the model development), understanding the impacts of different network characteristics, and understanding how stochastic input variables affect the model behavior.

Preliminary experiments helped increase my understanding of mechanisms in place as well as helping me to identify model shortcomings to improve the model in steps. More importantly, it helped me identify echoing leadership, which was not present in the literature. It also proved the importance of the social network in determining model behavior which led to the design of network experiments.

Network experiments were particularly very important since some researches see some network measures as a representation of social capital in a community. Network measures that were examined are population, density, degree centralization, and betweenness centralization.

Initial results showed that a higher population of communities or higher density contributes to reaching consensus at lower ecological pressure and higher emergence of echoing leadership, while consensus time increases. However, since it was against my intuition, I analyzed it further and found average connections per agent to be responsible in these three aforementioned trends of KPIs. Higher population, in fact, seem to increase the final ecological pressure while the emergence of echoing leadership is less prominent. Higher population decreases the emergent enabling leadership as well.

Degree and betweenness centralization measures without any doubt affect the model behavior, however, it seems that the aforementioned KPIs and these centralization measures have a nonlinear relationship that depends on population and density. Further analysis is needed to properly determine these relationships.

If only the network and the ecological structure change, there is a linear relationship between the emergence of echoing leadership, final ecological pressure and consensus time.

All in all, between the network measures that I chose based on preliminary experiments and suggestions by other researchers, average connections per agent seem to be the most important factor in determining the system behavior. I use average connections per agent instead of density because, at the same density, higher population increases average connections per agent which shows a different impact on the system behavior in comparison to when two scenarios of similar average connections per agent, yet different populations are analyzed and compared.

To understand the impact of heterogeneity of agents, prestige and farm size of agents were chosen from random distributions. Six different scenarios based on three different values for farm size inequality and two different situations in which whether the prestige of agents depends on the farm size or not was created.

I understood from analyzing the results of this set of experiments that higher inequality, in the limited range that was examined, leads to lower final ecological pressure and more prominent emergence of echoing leadership and enabling leadership. If in a community, actors' prestige depends on their endowment or farm size, the final ecological pressure increases and the emergence of echoing and enabling leadership is less significant. The important lesson from this set of experiment is that inequality and dependence of prestige on endowment affect the system behavior.

7.2. Academic contributions of this research

I discuss the academic contributions of this research in four points. They are the case study, theory development, adaptation of the SES framework to this theory, and modeling the emergence of leadership in communities.

The case study of Mojen is among the first academic studies of this interesting case in English. This case was particularly interesting because the reason behind their self-organization was not lack of water, but the conflict that was caused because of water loss. I also structured the relevant factors of this case using the SES framework in chapter 4.

For the theory development, I used different studies about leadership in collective action, leadership in communities and leadership in organizations. The first major contribution of this study was to synthesizing and creating an integrative framework. I accepted the enabling leadership as a leadership type that emerges in communities and I connected it to a theoretical lens and a definition that allows researchers to identify leaders. I also adopted a description of the role of leaders that is aligned with these concepts so that it is possible to understand why leaders are important and why their contribution matters. Moreover, this description of the role of leaders allows comparison between leadership manifestation of different actors.

The modeling phase allowed me to understand that this picture is not complete. Hence, I added the concepts of effective leadership and echoing leadership. Furthermore, I created a theory, that I called leadership for community development, to describe the connection between different concepts that I found through literature review and modeling.

By applying the SES framework to the LCD theory, I intended to give a structure to relevant factors of social-ecological systems and to help other researchers, who are familiar with the SES framework and practice it, to use the LCD theory for understanding and helping the emergence of leadership in the initiation of collective action in communities. This will be explained in more details in the next section. The adaptation required some changes on the scope and framing of two attributes as well as adding three new ones.

Modeling phase of this research had two contributions. The first one that I already mentioned is helping me in further developing the theory. It wouldn't have been easy to recognize the notions of echoing leadership and effective leadership without using the model. The second is providing a new approach toward modeling the emergence of leadership in communities. To the best of my knowledge, this was the first attempt at modeling the leadership as a property that emerges from influential interactions of actors. The model was also a proof of concept in a virtual laboratory for the LCD theory. In the modeling, I implemented the original idea of neutralizing agents, or part of their behavior, to find their effective leadership and enabling leadership contributions.

7.3. Using findings of this research in practice

Findings of this research can be used for two purposes of diagnosis and facilitating in practice. Diagnosis is done to understand the current state in the social-ecological system and to answer why collective action is not happening in that system with a focus on the role of leaders. Diagnosis can be the prerequisite step for the facilitation of collective action in communities. I have three general practical conclusions based on the findings of the research as well. The domain of application of these findings, as stated before, is beyond common-pool resources.

General implications of this research in practice

Throughout the whole process, any effort at strengthening the social network of the community can be fruitful, since the social network is important in giving attention to the problem, idea generation, idea elaboration, and idea promotion. Based on the results of the model, networking activities might be more important in bigger communities, since at higher population emergence of leadership seems to be lower and higher ecological pressure is needed to trigger agreement.

High inequality should not be seen as an absolute barrier. It is possible that in high inequality, big land owners have the incentive to be emergent leaders or at least be a smaller barrier in comparison to a satisfied medium land owner. This is aligned with some other researches over impacts of inequality on collective action. What I am trying to add is that these big land owners might even become leaders for change.

In communities, most effective leader might not necessarily be the person who is very vibrant and loud in promotion of an idea. Researchers or facilitators should look beyond this and observe the dynamics that are caused by the social network. Bridges between subgroups of the community might be much more effective and important. Moreover, based on the structure of the social network, a community might need more echoing leaders than visionary enabling leaders.

Diagnosis

To diagnose the reason behind lack of collective actions in communities to solve a problem can be done in the following steps:

1. First, it is required to understand the system. The SES framework can be useful for recording attributes of the system that are relevant to the emergence of leadership in the initiation of collective action in communities. Special attention should be given to collective choice institutions and the social network of the system.

2. Concerning the described innovation process as well as the general narrative (as depicted in figure 7.1), the researcher needs to understand which phase the system is going through.

3. If the innovation phase has not started, it is important to see if community members have recognized the existence of the problem. If not, the community might need problematizing leaders that influence the community members to give attention to the problem under study. The social network plays an important role in generating the idea as well. The idea generation phase can happen inside the community by an innovative community member who recognizes the problem and receives knowledge, ideas and different perspectives of the problem through his or her social network.

4. If the innovation phase has started, yet it is not progressing and there seems to be a dead-end, the researcher needs to find out if the previous steps are done properly. For example, despite the existence of an idea, the idea doesn't seem to match the problem well enough, or many community members still do not acknowledge the problem.

5. In case of a dead-end in the middle of the innovation process, there may be a problem at the current step of the innovation process as well. For example, the idea generator doesn't receive proper feedback and support from her or his connections in the social network to pursue the idea. Another example might be a situation in which potential enabling leaders do not have strong connections to other community members, or there is no key individual who can act as the echoing leader between different sub-groups of the community.

The examples that I mentioned are what I presume to be most probable. Of course, there may be many more reasons or obstacles that researchers need to find out based on the context.

Facilitating

Based on the diagnosis of the problems and obstacles, the facilitators can try to play the role that is missing or help some members of the community to do it. From the case interview, I understood that it is possible for an outside actor to take the role of leaders as well.

In the beginning, problematizing leadership is important since people need to recognize the problem, or if it is already acknowledged by the majority of the community members, it needs to receive priority. In the idea elaboration phase, a facilitator can help to make the idea that has emerged from inside the community to fit the problem perfectly so that there is higher reception for the idea. In the idea promotion phase, the facilitator, based on what is found to be lacking, can take the role an enabling or an echoing leader. Another option is for the facilitator to help potential enabling and echoing leaders to be more effective by helping them in framing and communicating the idea to other community members.

7.4. Applying LCD in a different institutional setting

Throughout this study, I emphasized on two institutional conditions for applying the LCD theory and the findings of this research. With some consideration, I believe it is still possible to apply the findings of this research in cases where there is an authoritative power in the domain of collective action based on operational institutions or when collective choice institutions give more decision making power to some community members on changing the operational rules.

In a case where there is authoritative power according to the operational institutions, the dynamic and the narrative of the process might change to some extent, however, the core concepts can be similar. Inclusion of a condition on operational institutions was mostly to simplify the creation of the complex concepts behind the LCD theory.

For example, imagine a pasture case where a group of elders decides on which sub-group of the community gets to use the resource for how long each week, but the collective choice institution requires a consensus for changing the operational institutions. In case there is dissatisfaction, this group of elders might just change the planning to deescalate the situation. In this case, the operational rule is not changed, yet there was an innovation process inside the group of elders. On the long run, this dissatisfaction might build up and result in a change in the operational institutions through the described innovation process as well, however, the elders might impact this process and change the dynamics of it by changing the planning of resource use very often.

In communities where collective choice institutions give higher decision-making rights over changing the operational institutions or over starting community-scale collective action to some community members, the LCD can be applied with consideration of different view on achieving necessary political capital.

For example, imagine a community that is facing water management issues, in which only a group of elders are allowed to change the management system. In this case, it is still possible that idea generation and elaboration happens by other community members who are not part of elders. They can also display echoing and enabling leadership. However, to start the adoption of an idea, all elders need to agree to the idea. Therefore, political capital is only achieved by convincing elder. Nonetheless, other community members can show effective leadership even by influencing and convincing each other as long as this influencing, through intermediary actors, leads to convincing elders. This perception is in line with the decision approach that is adopted for this research. Based on the decision approach, to see leadership, one must compare the actions with the outcome.

7.5. Limitations

At the end of chapter 4, it was discussed that all of the relevant factors identified in chapter 4 are not included in the model conceptualization. Some of these factors, like interdependence of agents, may cause interesting behaviors to emerge. Another important concept that is not taken into the account is the difference between weak and strong ties. From reviewing the literature on social networks, it became apparent that strong and weak ties can create different mechanisms. Tension and conflicts among actors which can lead to idea generation as well as leading by example are concepts that I included in the theory but I did not cover them in the model. These shortcomings don't mean the outcomes from this model are irrelevant, however, model results are providing information on the effects of a limited number of factors.

Mean enabling leadership and mean echoing leadership are indicators that I used for seeing the emergence of leadership. However, the mean of agents' leadership indicators might not be the best way to observe the emergence of enabling and echoing leaderships. There may be interesting patterns inside of each replication and the distribution of these leadership indicators may provide more information.

The model and theories are focused on only one single policy or decision-making arena. People might exchange their vote or decision making rights over different topics and their behavior might be completely irrational if only one policy arena is seen. Multiple policy arenas are not included since it will not be practical to model every possible interaction in a community for the sake of understanding the outcomes of one topic only. Including interdependence between different agents might be a way to represent this more complicated mechanism that exists.

Sensitivity analysis showed that only model constants that are directly or indirectly used for calculation of dissatisfaction (whether it is water dissatisfaction or potential dissatisfaction) might noticeably change model behavior. Even between these variables, only one of them, potential dissatisfaction limit, is important. This is because other model constants that contribute to the calculation of dissatisfaction are chosen purposefully and in relation to each other to create a wide distribution of dissatisfaction in the model. What matters is having a model in which the emergence of leadership and consensus (as the starting point of collective action) happens through the innovation process due to the dissatisfaction of some agents about their current situation. To see leadership it was needed to have satisfied agents which should be convinced and influenced. Consequently, regardless of why some agents are satisfied and some are dissatisfied, what comes after, especially in idea promotion phase which relates to enabling and echoing leadership, is more relevant and important.

Potential dissatisfaction limit is important unlike the rest because it directly affects the behavior of agents with big farm sizes. From the sensitivity analysis, it is known that higher potential dissatisfaction limit, at least around the value that is used in the base model, increases the final ecological pressure, the consensus time, the mean echoing leadership and the mean enabling leadership. Moreover, in stochastic experiments, this conceptualization of potential dissatisfaction led to many replications without the emergence of leadership. My suggestion is to make the formalization of potential dissatisfaction calculation continuous which is more consistent with the real behavior of people.

Idea elaboration and idea generation are also modeled very simply and cannot represent the full complexity of how actors generate and elaborate an idea in the real world, yet, since the focus was on leadership and influencing, this can be considered sufficient for this model. The current conceptualization of idea elaboration resulted in many replications of some scenarios of network experiments not showing the emergence of leadership since in those cases idea elaboration failed. I consider this the most important limitation.

In the design of final experiments, the stochastic experiments were done only using one network. The conclusions from these experiments are susceptible to be incomplete and it is necessary to repeat a similar set of experiments using different networks. Moreover, tie strength and preference of agents are still homogeneous in these experiments. I made these choices because the experiments were computationally expensive.

In the final network experiments, I removed the networks that had a bridge from the analysis. These networks showed different behaviors and are worthy of further analysis. Therefore, the discussed impacts of network characteristics on model behavior do not apply to networks which include a bridging actor. It is important to further analysis of these types of networks because, as explained in chapter 2, one of the important actions of leaders is bridging between different actors inside and outside of a community. Also, a higher number of replications will make it easier to distinguish the impacts of degree and betweenness centralization measures on model outcomes.

Both of these two final sets of experiments covered a limited range of input variables under analysis because of computational limitations. A higher number of scenarios can provide more information. This is possible with the same model without any improvements.

Despite all the mentioned limitations, the model outcomes still provided new insights and allowed the creation of new hypotheses that can be used to continue this research.

7.6. Recommendations for future work

In this final section of the study, I want to discuss my recommendations for future work, both on how to use findings of this study in different research approaches and on how to improve the model further. These recommendations are presented by how I conceive order of their priority and importance.

First of all, there are many new developed or newly applied concepts about leadership in communities. Although some studies connect community development projects such as grassroots innovations to complexity leadership theory and the concept of enabling leadership, the process described here to explain leadership emergence needs to be further analyzed and tested using case studies. To elaborate, studies are needed that can further validate whether the four phases of the innovation process and the emergence of leadership through this process happens in community collective action projects or not.

Model outcomes regarding impacts of inequality, the dependence of prestige on the endowment, and network characteristics on system behavior can be tested and validated in case studies. This can further validate the mechanisms and processes described in this study about the innovation process and leadership in communities.

Regarding the impacts of network measures on idea promotion phase, some group experiments can be designed in which people are positioned in a social network and can only interact according to this network. Even the strength of connections can be conceptualized as the time limit of interaction between people. These types of experiments might change the perception that exists about the effects of population and network characteristics on the possibility of overcoming collective action problems. Leadership emergence can be also observed in this process. Rules of these experiments can be derived from the case studies that were suggested previously.

Next on the order of priority is improving the model based on its limitations.Improving idea elaboration is the top priority here. This can be including a threshold above which agents can create a new idea. So if idea elaboration of an agent fails due to having satisfied agents, another agent will attempt to create and elaborate an idea. Improving potential dissatisfaction conceptualization comes next. The proposed case study can help to create a better conceptualization for this. Next improvement on the list is making satisfied agents active against change. This seemed to be important from the case interview. After these changes, more detailed experiments on the impacts of heterogeneity of agents as well as impact of different social network characteristics can give valuable new insights. From the results of new experiments that will be designed to test these hypotheses, the next steps should be decided.

Other possible ways to continue this research are adding the possibility of multiple ideas in the system or adding details to ideas and connecting them to some agent characteristics. Idea elaboration process can be more than majority vote and it can define details of a new idea. This can be based on some agent characteristics as well. For this to be possible ideas need to be more complex and include some information on how the system will be changed by the new idea. This way it will be also possible to model full adoption of idea and to check whether an idea can be successful or not. At that stage, it will be possible to model and observe the management of the new system.

A

Modeling steps documentation

In this part of the report the modeling steps that are done to reach the final model presented in chapter 5 is explained here. This appendix is written in a manner to be understood independently, therefore, the reader might observe some overlaps between this appendix and chapter 5.

A.1. A simple model of the leadership emergence

The agent-based model created here needs to have farmers as agent and a representation of ecological system which provides water to the farmers. Farmers interact with each other and the system in each time step. These interactions produces the emergent behavior of the system. Farmers are positioned in a social network. In this section, the simple model created to demonstrate the emergence of leaders, as the desired emergent behavior, and its results is presented. Model implementation is done in NetLogo and the aforementioned time step is called a tick according to this modeling environment.

Conceptualization

To model influencing, the power of this action and the connections through which people influence each other should be conceptualized. In this step, this power is taken as a function of the prestige of influencer, content of the message, and the strength of ties between the influencer and the subject. It is assumed that agents only influence others who are connected to them and new connections for the sake of influencing is not created. The effect of content of the message relates to how appealing the idea is for the subject. In the model, only one idea possibility is considered, nonetheless, equations presented here can be easily modified to be applicable to a case of multiple competing ideas. Another factor assumed to contribute to the power of influencing is the dedication of an agent toward an idea. This factor can be understood as an illustration of agents' willingness to utilize its influencing power along with how an influncer's dedication is received by the subject. To clarify, preaching an idea without much believe in it will be less effective.

An agent can be influenced by multiple other agents, however, the evaluation of the content of the message should not be repeated. Thus, power of influencing should be broken to two parts of the *exerted influence* of the influencer on the subject and the *personal conviction*. This is called the personal conviction because the subject evaluates the content of the message based on personal beliefs. Dedication itself can also change when agents influence each other. For practical reasons, the dedication of an agent in the beginning of each time step (pre-dedication) is separated from the end of it (post-dedication). Therefore, exerted influence ($EI_{xy,t}$) of agent x (the influencer) on agent y (the subject) at time step t will follow equation A.1.

$$EI_{xy,t} = (\eta_{Ps} \times Ps_x + \eta_{TS} \times TS_{xy}) \times PreDed_{x,t} \tag{A.1}$$

where:

- $x \neq y$;
- Ps_x is the prestige of the influencer;
- η_{Ps} and η_{TS} are weights of factors and they sum up to one;
- $PreDed_{x,t}$ is the pre-dedication of the influencer at time t.

This formalization of exerted influence means farmers will only exert influence on others when they are dedicated themselves and the influencing power is a function of dedication. Use of tie strength points out to the fact that exerted influence only happens when two agents are connected in the social network directly.

Personal conviction of agent is evaluated positively if the agent believes an idea is beneficial to change of its situation and if the agent is not happy with the current status. Of course, this is only done by an agent if the agent is familiar with an idea. A more prestigious agent may value its own personal conviction more than exerted influences on it. In other words, instead of using absolute value of influencers' prestige, it should be put to perspective against an agent's own prestige. Personal conviction of an agent at time t ($PC_{a,t}$) is the evaluation of the content of the message by the subject (as the subject of influences exerted by other agents) and is calculated based on equation A.2.

$$PC_{a,t} = (\eta_{Dis} \times Dis_{a,t} + \eta_P \times P_a) \times Ps_a \tag{A.2}$$

In this equation,

- η_{Dis} and η_P are weight of factors and $\eta_{Dis} + \eta_P = 1$;
- $Dis_{a,t}$ is the dissatisfaction of agent a at time t, which represents how much an agent wants to change the current situation. this is also why personal conviction is a dynamic variable;
- and P_a is the preference of agent a about idea i, representing its personal belief if it sees idea i as beneficial or not.

Exerted influences and the personal conviction determine the dedication of an agent about an idea. The mathematical configuration of this concept can be seen in equations A.3 and A.4.

$$PreDed_{y,t1} = \eta_{EI} \times \sum_{x,x \neq y} EI_{xy,t0} + \eta_{PC} \times PC_{y,t1} \tag{A.3}$$

$$PostDed_{y,t1} = \eta_{EI} \times \sum_{x,x \neq y} EI_{xy,t1} + \eta_{PC} \times PC_{y,t1} \tag{A.4}$$

Again η_{EI} and η_{PC} are weights of factors and their sum is one. $\sum_x EI_{xy,t}$ is aggregation of all exerted influences on agent y, where $x \neq y$. When all agents are dedicated to the idea at the end of a time step ($PostDed_{a,t} > 0$), consensus is reached and the idea will be adapted. This is model presentation of achieving necessary capitals, which is limited to a specific case of achieving required political capital in this model. The differentiation between pre- and post-dedication allows calculation of change in dedication caused by exerted influences only, as well as checking the political capital behind an idea at the end of each time step.

Conceptualization of dissatisfaction is where the ecological system becomes relevant and connected to the social system. Agents are dissatisfied when they don't receive enough resources, which is water in this case. Enough water can be defined by the size of their farm, which is their endowment and can be a heterogeneous static state variable of agents. Each unit of farm needs a certain amount of water, which is called $RWUF$ (Required water per unit farm).

$$Dis_{a,t} = RWUF \times F_a - AW_{a,t} \tag{A.5}$$

where,

- $-1 \le Dis_{a,t} \le 1$
- F_a is the farm (endowment) of agent a;
- $AW_{a,t}$ is the allocated water to agent a at time t;

To model allocation of water, the model environment generates the resource and provide agents access to the resource based on their location and their share (their farm size) in their turn. An agents turn is based on which block they belong to, and the random order of block in getting access to water (see chapter 4, the Mojen case). The environment in the model is not implemented in this manner to replicate the case of Mojen, the intention is to capture the main interactions that might happen in such water common pool resource, to base agents' interest based on some characteristics of themselves and their farms, as well as to make sense of the results.

Location of each agent specifies which branch of canals they are in and in which order they residing in the branch. Agents in the same branch are considered neighbors. To simplify I call branch numbers as columns and clarify they are in a branch as rows. As agents get further away from the start of canals (either by rows or columns) there is more water loss. To elaborate, the total water created at the source is distributed to the agents at different branches based on their total share, i.e. their endowment. As the water passes a row or column a constant static amount of water is lost. This is called water loss per step.

Lastly, how an idea itself is created is an important notion to conceptualize for the model. In chapter 2 it was discussed that idea creation depends on tension (from inside a group or from outside) or disequilibrium in the system, as well as the social network characteristics. Tension is a dissatisfactory factor that innovation can help to overcome. Looking at the same subject from the public entrepreneurship perspective discussed in chapter 2, the disequilibrium setting means there are some people who are not satisfied with the situation and desire change. Thus, dissatisfaction is chosen as the factor that contribute to idea creation and dedication to an idea. The other factor that is used in this model to conceptualize the possibility of idea generation is the number of ties. It is more ideal to differentiate interdependence ties from friendship ties and use the former in calculating the possibility of idea generation, however, in this first model, only one connection type is considered. Although the mentioned factors contribute to the possibility of idea generation, in this model it is assumed this will happen by the agent with the highest idea generation possibility ($IGP_{a,t}$) after the calculation of dissatisfaction in each tick as long as the idea is not present. Idea generation possibility is calculated through the following equation.

$$IGP_{a,t} = Dis_{a,t} \times NT_a \tag{A.6}$$

In equation A.6, NT_a is the number of ties of agent a and is calculated just by counting the connections of an agent in the social network and is not a state variable of agents. After idea generation, idea elaboration phase will happen. Model formalization of this concept is taken to be majority vote of the agent who came up with the idea and those who are connected to it. They vote based on their personal conviction about the idea.

Going back to the start of this section, identifying the emergence of leaders by influencing was the goal and the initial point of designing this model. The main concept used to represent it is the exerted influence, nonetheless, this is not enough to show how much an agent contribute to the actual change in the subject's dedication change, because the subject of an influencing action might already be completely dedicated. To find the actual influence of an agent x on agent y ($AI_{xy,i,t1}$) at each time step, equation A.7 is used.

$$AI_{xy,i,t1} = \frac{(PostDed_{y,i,t1} - PreDed_{y,i,t1}) \times (EI_{xy,i,t1} - EI_{xy,i,t0})}{\sum_{z,z\neq y}(EI_{zy,i,t1} - EI_{zy,i,t0})} \tag{A.7}$$

where:

- $x \neq y$;
- and $0 \le AI_{xy,i,t1} \le 1$.

The aggregate actual influences ($AAI_{x,i,t}$) is the sum of all actual influences on different agents over all the past time and it is calculated based on equation A.8.

$$AAI_{x,i,t1} = \sum_{y,x\neq y} AI_{xy,i,t1} + AAI_{x,i,t0} \tag{A.8}$$

The aggregate actual influences, post-dedications of agents, the agent who created the idea, the time until reaching the consensus and the final ecological pressure which was necessary to reach consensus are outputs of interest. This ecological pressure can be implemented by reducing the available water in the model. These outputs will be analyzed in the next section. Figure A.1 shows the schematic representation of this model's input and output. Table A.1 provide the list of variables used in the model and their characteristics. From this table, it can be seen that connections or ties between the agents are modeled as a link. This is also true for the exerted influence. The number of ties is not an agent variable, however, the connection themselves are input to the model (see figure A.1). Input variables of agents and the environment mentioned in figure A.1 are independent variables of table A.1.

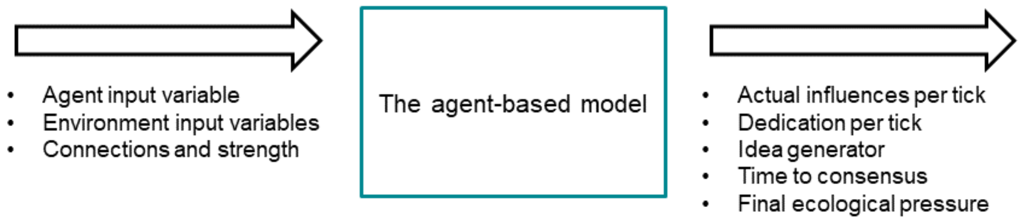


Figure A.1: Inputs and outputs of the simple model

Table A.1: Variables used in the model

Name	Type	Owner	Independent?
Total water (TW)	Dynamic	Global	Yes
Water loss per step (WLS)	Static	Global	Yes
Required water for endowment unit ($RWUF$)	Static	Global	Yes
Weights of factors (η)	Static	Global	Yes
Farm (F_a)	Static	Agents	Yes
Prestige (Ps_a)	Static	Agents	Yes
Location (column and row)	Static	Agents	Yes
Preference (P_a)	Static	Agents	Yes
Block	Static	Agents	No
Personal conviction ($PC_{a,t}$)	Dynamic	Agents	No
Dissatisfaction ($Dis_{a,t}$)	Dynamic	Agents	No
Pre-dedication ($PreDed_{a,t}$)	Dynamic	Agents	No
Post-dedication ($PostDed_{a,t}$)	Dynamic	Agents	No
Allocated water ($AW_{a,t}$)	Dynamic	Agents	No
Idea generation possibility ($IGP_{a,t}$)	Dynamic	Agents	No
Aggregate actual influences ($AAI_{a,t}$)	Dynamic	Agents	No
Tie strength (TS_{xy})	Static	Tie link	Yes
Exerted influence ($EI_{xy,t}$)	Dynamic	Influence link	No
Actual influence ($AI_{xy,t}$)	Dynamic	Influence link	No

Model verification

In this section, tests that were implemented to verify the model are explained. The concepts that are proven here and not changed in the following steps do not need to be verified again. Verification is attempted to prove the model implementation is doing what was intended during conceptualization and formalization.

Before verifying any concept, it was confirmed that there are no unwanted stochastic behavior in the results and many runs of same scenario yield the same outcomes.

The first concept to check is dissatisfaction computation. For this purpose agents' allocated water and their dissatisfaction were added to agents' label in the NetLogo implementation. It was proven that dissatisfaction is a function of the allocated water as intended in equation A.5. Moreover, the allocated water of agents was tracked and compared with expected values calculated outside the model implementation.

The values for the idea generation possibilities were observed in a similar manner to verify that this variable is calculated correctly and it follows the number of connection and the dissatisfaction as desired. Nonetheless, this verification test reveals a problem in the model. If the total water is below 38, the idea generator will be random, since there will be more than one agent with the maximum idea generation possibility. This shortcoming, however, doesn't cause any issues in this step of the model. This is because as you can see in the model setup and results section of this model there is only a few scenarios where the idea generation happens when the total water is less than 40. Care is taken in those scenarios in comparison of results. This issue is resolved in the next step of the models.

The next concept implementation to verify is the elaboration of ideas. The rule for the elaboration phase was majority vote of the idea generator and its friends about the idea based on the calculated personal conviction. Therefore, personal conviction of agents are displayed and tested in different scenarios that are of importance to the experiments.

Next item to verify is the implementation of exerted influence. First it was successfully checked that only agents which have a positive pre-dedication are exerting influence and they exert influence on all their connections.

Another part of this concept that needs to be checked is the value of exerted influences itself. During the experiments (see the result section of this model) it was observed that aggregate actual influences follows the changes in the prestige and the tie strength of agents. Aggregate actual influences was used to avoid taking into account the exerted influences of an agent if the subject was already fully dedicated. However, in none of the scenarios there was any fully dedicated agent. Therefore, the sum of exerted influence of an agent multiplied by its weight in calculation of dedication ($\eta_{EI} \times \sum_{y,x \neq y} EI_{xy}$) and its aggregated actual influences should be the same in all scenarios, which is true.

Furthermore, since aggregate actual influences is calculated based on changes between post-dedication and pre-dedication and exerted influences cause this change, it is possible to say the change in dedications of agents are implemented properly. Comparison of outcomes confirms this argument as well. The step-wise reporting of post-dedication and aggregate actual influences allowed a comparison of these values to make sure the connection between dedication and exerted influence is working correctly. Since it is proven aggregate actual influences is a constant fraction of exerted influences for an agent, this comparison was possible.

Despite the fact that full dedication, that is pre- or post-dedication being equal to one, never happened, I decided not to remove or change the formalization aggregate actual influences from the model, since this value represents the actual changes in dedication. Moreover, any other model that is based on this simple model will not have an issue if an agent becomes fully dedicated.

In almost all of the experiments, agents have different dissatisfaction and many of them are done with key individuals that have different prestige or preference. From

Changes that are done to create the key individuals in the next section are straightforward and except for the change in the farm size, the rest do not require any extra verification. The sanity and explainability of results themselves are a proof that these changes are implemented properly. In verification of farm size change it was observed that there is a very small error due to NetLogo's inaccuracy in calculation of small numbers. This error (less than 10^{-15}) is negligible.

The simplicity of the model made its verification very easy as well. This is another proof that choosing a step-wise modeling approach was right. It is important to note there is no need to verify model behavior in extreme ranges of input variables, since in the model setup and experimentation a limited set of values are used. The logic behind this design is explained in the next section.

Model setup

Outputs and inputs of the model should be compared to gather insight on how different outputs are produced given the inputs and the concepts used in the model. Hence, this is very important to design input scenarios in a way that help the modeler to answer the research question. Here, I want to see with what characteristics of agents and the social network (the inputs), leadership patterns (i.e. a noticeable difference in actual influencing) emerge and an idea is adapted.

In other words, I want to use the input to create different types of *key individuals*, and then observe if these key agents have been useful to adaptation of an idea and if so, which type or combination of them are more beneficial to adaptation of an idea. A key individual is considered useful when in comparison to homogeneous agents (the base model), adaptation of an idea happens faster or under less ecological pressure. Along with these patterns of interest, the model behavior will be compared to the theoretical backgrounds of chapter 2, to check if those theories can be recognized from the mode.

To gain the insights explained here, I am avoiding analysis of many experiments created by stochastic variables, because the understanding of the model is not sufficient enough to comprehend complex emergent pattern and to connect correctly to a wide variety of input variables. Instead, I create some designed experiments to achieve this basic understanding. Indeed the whole point of this simple model was to get here.

These designed experiments and scenarios are used to check plausibility of some hypotheses. These hypotheses are:

1. If all farmers are given homogeneous attributes, there won't be any observable emergence leadership patterns.
2. If a dissatisfied farmer has more prestige, reaching a consensus will be faster and at a lower ecological pressure, or in other word, easier. Dissatisfied agents are usually at the end of a branch.
3. If a dissatisfied farmer has more connection, reaching a consensus is easier.
4. If a satisfied farmer has more prestige, it will be harder to persuade it, therefore, it will be harder to reach consensus.
5. If a farmer has, or several farmers have higher preference towards the idea, i.e. they believe the idea is useful for them, reaching consensus will be easier, because they will be more dedicated to the idea.
6. If a farmer has, or several farmers have higher endowment or farm size, it will be easier to reach consensus, since they will be more dedicated.
7. If a satisfied agent has more connections it will be easier to reach consensus.
8. Existence of any agent with higher tie strength makes reaching consensus easier.
9. The more dissatisfied or satisfied a farmer is, the more prominent the aforementioned behaviours of the previous hypotheses will be.
10. The combination of aforementioned differences in agent behaviors will create an aggregate behavior. For example, if two farmers with higher prestige exist in the system, one of them satisfied and the other dissatisfied, they will neutralize each others' effect on the system level behavior.

Consequently, independent input variables are homogeneous in the base model. In scenarios, key individuals are created by making one or multiple independent variables, except for the location and global variables, different from the rest. Location of an agent does not make it a key one, however, it is important to experiment with the key individual at different locations.

User of the model can simply choose at what location the agent with higher farm size, more prestige, stronger ties, more ties, or different preferences exist. The social network of agents are predefined and when a user chooses one of agents at these locations to have more ties, again based on a deterministic algorithm, new ties are added to the network. To add connections to the social network of an agent it will be connected to the first agent of other columns, based on the user's choice either from the end or beginning of branches, which they are not yet connected to. This will result in an increase of 7 to its number of ties.

Total water, which is a dynamic input, has the starting value of 50. At any tick that the difference between the summation of all agents' post-dedication and the summation of all agents' pre-dedication is less than 0.00001, that is when the post-dedication and pre-dedication is almost the same for all agents, the total water will be reduced by 5. This small number is chosen instead of using equality because NetLogo is problematic at calculation of very small numbers and this way numerous unnecessary steps can be avoided, making the simulation faster.

When an agent's farm is increased, it will gain 0.1. To keep the total block share and the ecological system similar to other experiments, same amount of farm size will be deducted from this block's farm size by dividing it over other members of the block. In this manner other members of the block will be still in a similar condition to other experiments.

The starting values used in model follow the table A.2. In the next subsection it is explained for checking validity of which hypothesis these values are used.

Table A.2: Initial values of inputs used in the model

Name	Owner	Base model initial value	Initial values in experiments
Total water	Global	50	0 and 50
Water loss per step	Global	0.15	0.15
Required water per unit farm	Global	2	2
η_{Diss}	Global	0.73	0.73
η_{P}	Global	0.27	0.27
η_{EI}	Global	0.6	0.6
η_{PC}	Global	0.4	0.4
η_{PS}	Global	0.5	0.5
η_{TS}	Global	0.5	0.5
Farm	Agents	0.25	[0.23, 0.35]
Preference	Agents	0.25	0, 0.25 and 0.5
Prestige	Agents	0.25	0.25 and 0.5
Tie strength	Tie link	0.25	0.25 and 0.5

Results

In this subsection the results of experiments done to observe if mentioned hypotheses of the previous subsection are correct or not are presented. First the results from the base model are shown. Two top outputs of figure A.1 are shown in plots. These are aggregate actual influence and post-dedications of farmers (see figure A.2 and A.3).

Aggregate actual influences are shown as bar plots because at every step the new actual influences of each agent added to its aggregate actual influences, hence, it can show step by step increase of this value. On the other hand, post-dedication is calculate at every step, regardless of the previous value, and therefore, although it is increasing, I decided to plot it as points.

In these figures, each color represent one step in the model. As it can be seen in either figure, changes are not same in each step. Negative dedication of some agents in figure A.3

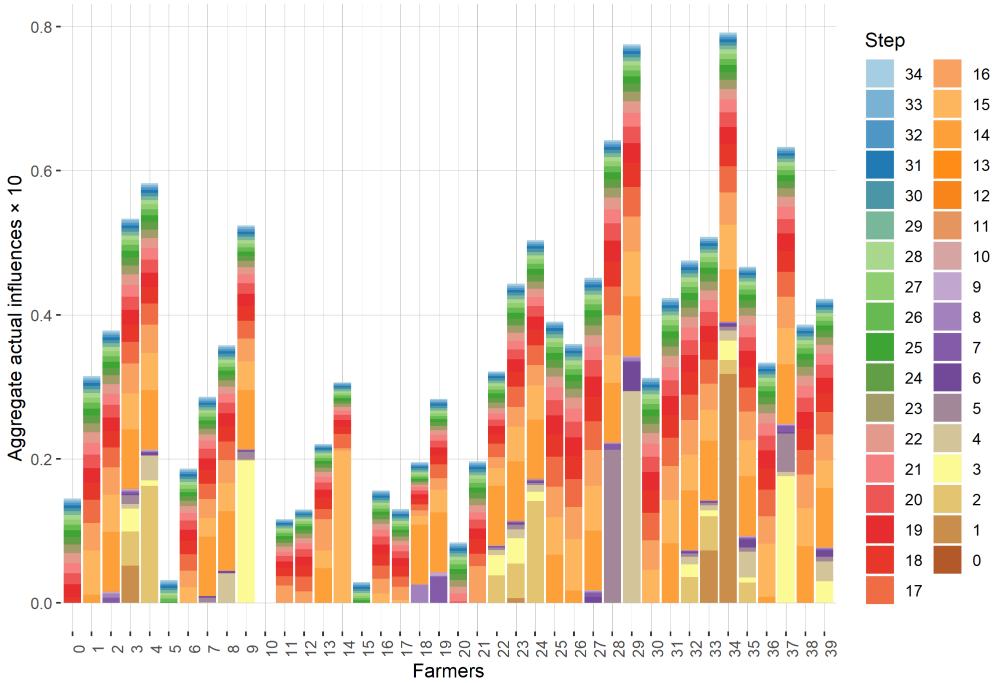


Figure A.2: Aggregate actual influences of farmers multiplied by 10 in the base model

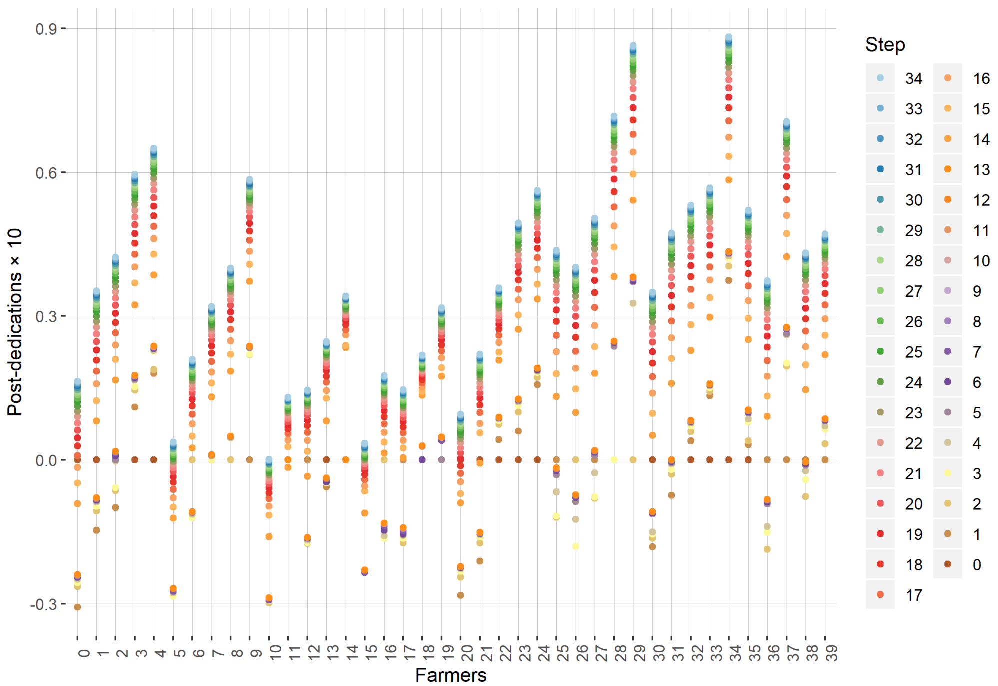


Figure A.3: Post-dedications of farmers multiplied by 10 in the base model

is due to their satisfaction in the environment. After 35 steps consensus was reached and post-dedications of all farmers became positive. A more detailed look at figure A.3 helps to understand that some agents report zero post-dedication for some initial steps, because it takes time for the information to reach them. In other words, they are not directly connected to the idea generator, thus, the agents that are in between need to exert influence on each other until all agents are influenced and as a result are *familiar* with it. In the base model, and most of what follows, farmer 34 is the one who created the idea. In the upcoming experiments, if it is not specified, the agent who created the idea is farmer 34.

In the base model scenario, the initial total water is 50. As you can see from from figure A.3 the dedication reported for step 0 (the first step of the model) is zero, because, agent 34 created the idea, but the elaboration failed, due to satisfaction of most of its connections. The initial value of all dependent variables in the model is zero. It is good to reemphasize that elaboration is majority vote of personal convictions, which is dependent on satisfaction and preference. Table A.2 shows that dissatisfaction is more important than preference (η_{Diss} is more than η_P). Due to no difference between pre-dedication and post-dedication water is decreased to 45 in the beginning of the next step. This resulted in a successful elaboration of the idea created by farmer 34.

In the next steps, dedicated agents influence other agents. This results in a feedback behavior. To elaborate imagine the fallowing situation. At time t farmer A influenced farmer B resulting in a positive post-dedication for farmer B. Pre-dedication of time $t + 1$ for farmer B is its post-dedication at time t. Farmer B influences all its connections, including farmer A. Now farmer A has a bigger post-dedication at time $t + 1$ because of exerted influence from farmer B and therefore, it will exert influence on farmer B with a higher influencing power. These loops will continue for all agents until consensus is reached or there is no meaningful difference between post-dedication and pre-dedications of agents. Smaller changes in post-dedications and aggregate actual influences that follow the bigger increment in the previous figures are because of this feedback effect. In my opinion, this is a good representation of how dedicated people of a community become more steadfast by supporting each other.

At step 14 there is a jump in post-dedication of agents according to figure A.3. This is the point where it became obvious that consensus can't be reached at this amount of water, because some agents are very satisfied with the current situation. Therefore, again the model environment decreased the total amount of water to 40. This amount of ecological pressure is enough and after some steps and thanks to the feedback effect, conses is reached.

As expected, the patterns of the outcomes from figures A.2 and A.3 are similar. Because aggregate actual influences is a function of pre-dedication and itself affect the post-dedication. Post-dedication of a time step is the pre-dedication for the next time step.

There are some other interesting insights to be gained from these pictures. Agent 0 has a bigger satisfaction (negative dissatisfaction) than agent 10, and hence a bigger negative dedication. However, comparing to agent 10, agent 0 became dedicated to the idea sooner and it is more dedicated at the end. It is due to different farmers that they are connected to. Farmer 0 is connected to more dedicated farmers in comparison to agent 10. So if agent 10 was had more or stronger connections to very dedicated farmers, the system would have reached consensus sooner.

A question might rise about the reason for heterogeneous outcomes of some homogeneous agents. It can be explained by considering farmers' position in the system, their block and their social network. The first two factor cause agents to have access to different amount of water, resulting in varied dissatisfactions. Moreover, although the agents all have six connections in the base model, they are connected to agents who have different dissatisfaction. The final factor that needs to be considered is the agent who has created the idea. In the base model it is not important because of many steps that are taken after the creation of the idea, nonetheless, importance of this factor will become more obvious in the next scenario.

In the end, I want to discuss the most important emergent pattern expected of the model, leadership. The conceptualization for this step was started by a focus on the issue of leadership and leading and choosing influencing, or to be more exact in model terms, aggregate actual influences as the indicator for leadership. From figure A.2 it is observable that all agents except for farmer 10 exerted some influence on others, some including farmers 28, 29, 34 and 37 did so more than others. Are they leaders? Certainly! According to the definitions I used, act of leading is meant to change interests of another person towards a common interest and that is what's happening here.

Yet, the bigger question is if it is possible to observe enabling leadership from this model outcome. To recap, enabling leaders are individuals who have a vision and are persistence toward reaching it. They influence others, through negotiations or other means, to gather the necessary capitals for adaptation of the idea. In the conceptualization of community leadership for development, I consider enabling leaders as those who make gathering the necessary capitals for collective action, whether it is consensus or money, easier, hence, they are indispensable for possibility of collective action. In this model, it will mean that an enabling leader is absolutely necessary to reach consensus at the same level of ecological pressure.

One shortcoming of the model becomes obvious here, it cannot capture the emergence of enabling leaders since no indicator here is suitable for that purpose. To be able to identify the enabling leader it is important to find out which agent is actually pushing the idea by creating the vision and is persistent in the way of achieving it. I believe the personal conviction of agents is a good indicator for this purpose. Dedication, on the other, is not suitable, because part of it comes from what others have influenced an agent to like and if that influence goes away what remains is only the personal conviction. In fact, any exerted influence or change in dedication is either because of personal conviction of the influencer, or the personal convictions of other agents (or itself) that are now part of the influencer's dedication. To put it simply, personal convictions are like sound sources that are echoed (possibly even stronger) by exerted influences of other agents. As a result of this issue, I decided to add a measure of enabling leadership based on personal conviction for the next modeling step.

All in all, aggregate actual influences are taken to be the metric of leadership, and based on this indicator, different levels of leadership can be seen in the base model. The reason behind the heterogeneity of results is already discussed. Nonetheless, to see if the first hypothesis can be accepted or rejected another experiment where there is no variation in allocated water is performed. Figures A.4 and A.5 show the outcomes of the model for the scenario with no water, which is designed to cause the same dissatisfaction among all farmers. In this scenario the idea is generated by farmer 36.

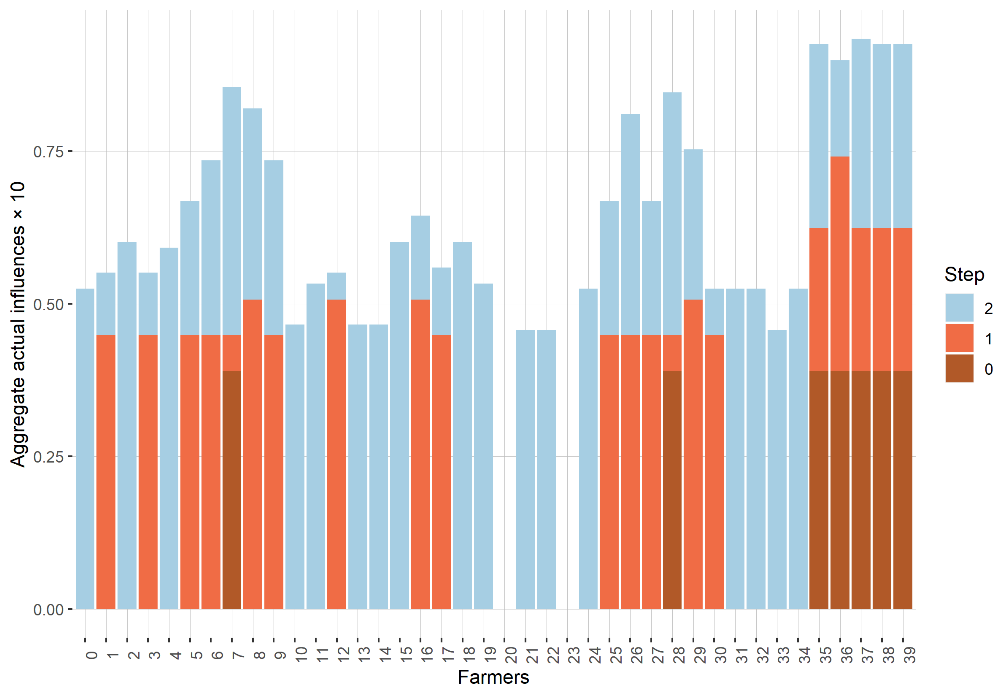


Figure A.4: Aggregate actual influences of farmers multiplied by 10 in case of zero total water

In this scenario, the aggregate actual influences of some agents, mostly those who are connected to the idea generator, are more than others, however, the difference with the average of aggregate actual influences is not significant.

Combining the results from these two experiments it is possible to gain insights about the first hypothesis. Leadership should not be seen as a zero-one possibility, people show different degree of leading others, which not only depends on their own characteristics, but

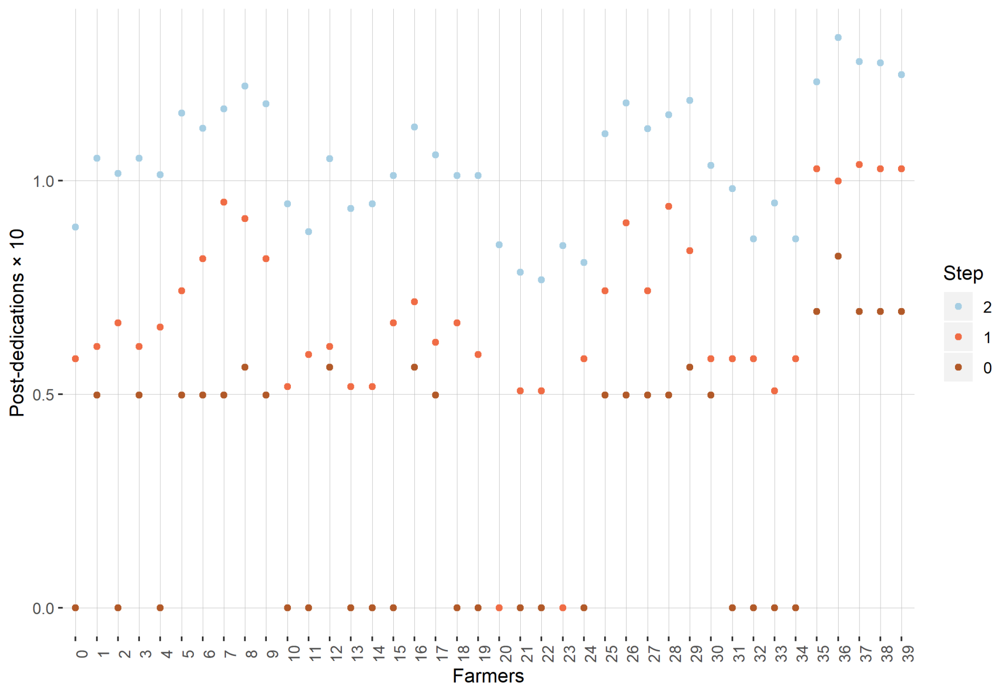


Figure A.5: Post-dedications of farmers multiplied by 10 in case of zero total water

also on the environmental and social network features. Even when all people have the same number of connections, some might have more influence in the community just due to their position (being closer to the idea creator) in the social network. Thus, the first hypothesis is rejected. It is possible even for homogeneous agents to show observable signs of leadership, although it might not be significant. Nonetheless, if the agents have the same environmental situation as well, emergent patterns of leadership are even less prominent.

This calls for another point of criticism of the model. Although, it is possible to see who had exerted more influence, it is not possible to know how necessary an agent's influence has been. It is more important to know if an agent had not influenced anyone, if it would have been possible to reach the consensus at the same ecological pressure. Therefore, in the next iteration of modeling in addition to the indicator for enabling leadership, it is necessary to add an indicator for the importance of an agent's leading (influencing).

Figures A.6 and A.7 relate to the experiment done to check correctness of the second hypothesis.

Even when farmer 34 has more prestige consensus is reached when the total water is 40. Notably, the total numbers of steps required to reach the consensus seems more, however, a closer look shows that after water is reduced to 40 at step 30, only 7 more steps is required to reach consensus, while in the base model 20 more steps was done until there was consensus about the idea.

Farmer 34, as the creator of the idea and the agent with the higher prestige, has a significantly higher aggregate actual influences, which is, of course, accompanied with a similar patter of post-dedication. Similarly, if another dissatisfied agent, who is not the idea creator, has more prestige, consensus is reached faster and the agent with the higher prestige has a considerably higher aggregate actual influence. This means the second hypothesis accepted and the agent with the higher prestige emerges as an undeniable leader. It is interesting to see that although aggregate actual influences pattern is following the post-dedication pattern, the difference between aggregate actual influences of agent 34 and other are amplified in comparison to the differences in post-dedication.

Hypothesis three need different experiments since depending on the key agent being connected to satisfied or dissatisfied agents different behaviors will emerge. Six different scenarios are experimented here.

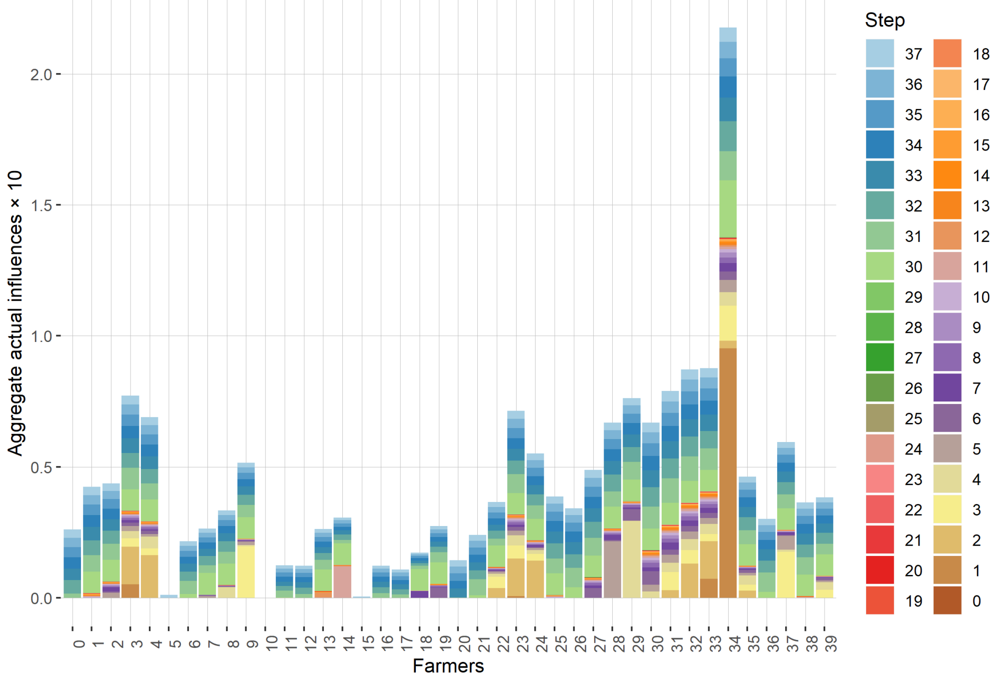


Figure A.6: Aggregate actual influences of farmers multiplied by 10 when farmer 34 has twice prestige of other agents

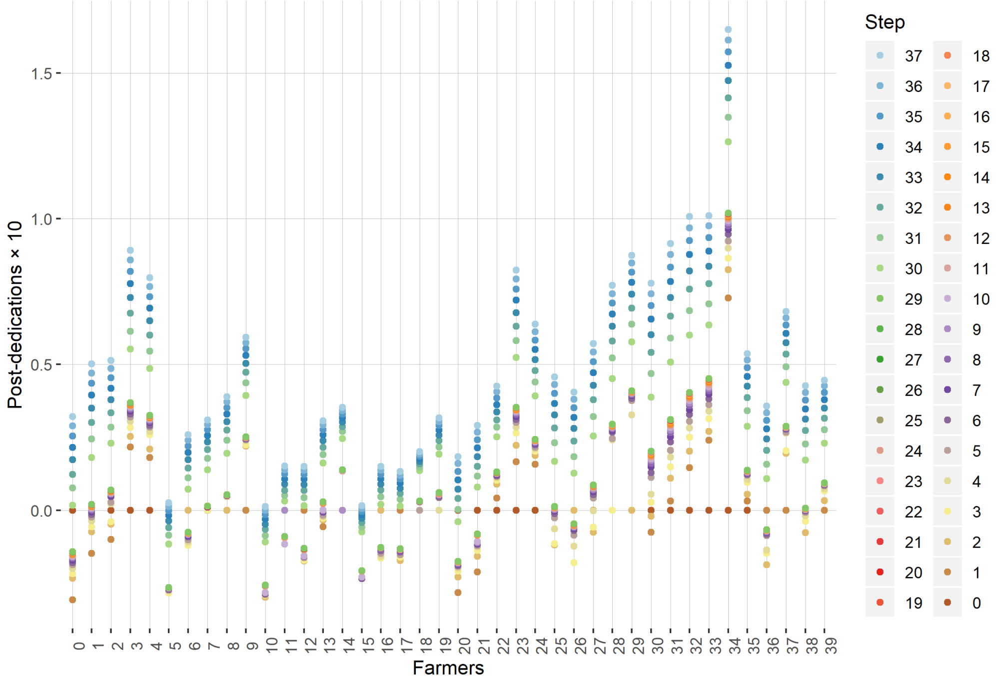


Figure A.7: Post-dedications of farmers multiplied by 10 when farmer 34 has twice prestige of other agents

In the first scenario, farmer 34 is connected to satisfied agents at the beginning of each branch. Again farmer 34 is the idea generator, yet elaboration fails until the total water is reduced to 35! This is simply because the majority vote of connections of farmer 34, who are mostly satisfied, will be against the idea. After elaboration only two more steps is required to reach consensus.

Figure A.8 show the aggregate actual influences of different agents in the second scenario,

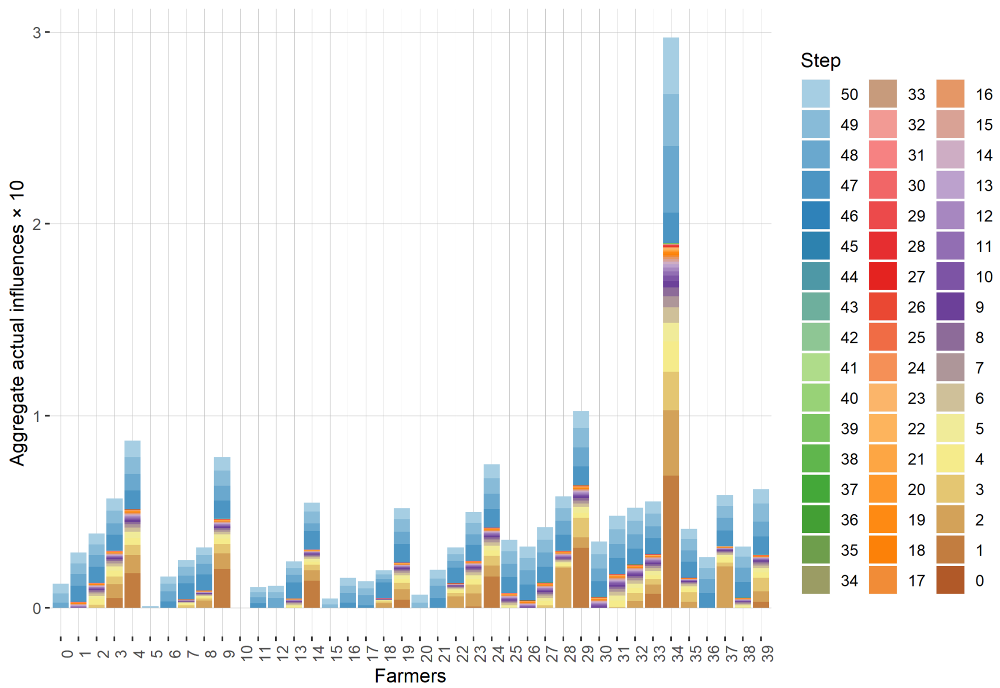


Figure A.8: Aggregate actual influences of farmers multiplied by 10 when farmer 34 has seven extra connections with other dissatisfied agents

where farmer 34 has more connections again, but this time to the other dissatisfied agents at the end of branches. Similar to the discussion of the experiment for the second hypothesis, here, number of steps until achieving consensus are high, however only 3 more steps are done after reduction of the total water to 40. In fact, the high number of steps done when the total water is still 45 shows the high leadership potential of farmer 34. The post-dedication outcome is not shown due to its low added value. Similar to the difference between figures A.6 and A.7, in this scenario, aggregate actual influences is just exaggerated pattern of post-dedications.

The next two scenarios experimented are where farmer 29 is chosen to have more connections, this agent becomes the idea generator (look at equation A.6) and the outcomes will be similar to the last two scenarios explained for this hypothesis.

In the fifth scenario, farmer 24 is given more connections to other dissatisfied farmers at the end of branches. Figure A.9 shows that this agent is the distinguished emergent leader in this scenario. Farmer also has more dedication than other agents. Three steps after the total water is reduced to 40 consensus is reached.

The results in the last scenario of experiments done for hypothesis three is more interesting. In this scenario farmer 24 is connected to farmers in the beginning of branches, who are mostly satisfied. Again farmer 24 is the noticeable leader, yet its dedication is less than two other agents. This can be explained by the fact that most of its extra connections are satisfied and will not provide any supporting feedback (figures A.9 and A.11). This smaller post-dedication results in a weaker realization of leadership as well (compare figure A.10 and figure A.9). Yet again, 3 more steps after reduction of the total water to 40 consensus is reached.

From these six scenarios, it can be inferred for the third hypothesis that the effects of a more connected agent is not just dependant on if the agent is satisfied or not. It is important to also consider if the agent is an idea generator or not, as well as the social network in the system. Connecting an idea generator to satisfied agents might hinder successful elaboration. Contrary to my expectations there is no extra benefit if an dissatisfied agent with more connections than other agents, who is also not the idea generator, is connected to the satisfied agents instead of being connected to other dissatisfied agents. In both cases, the behavior is

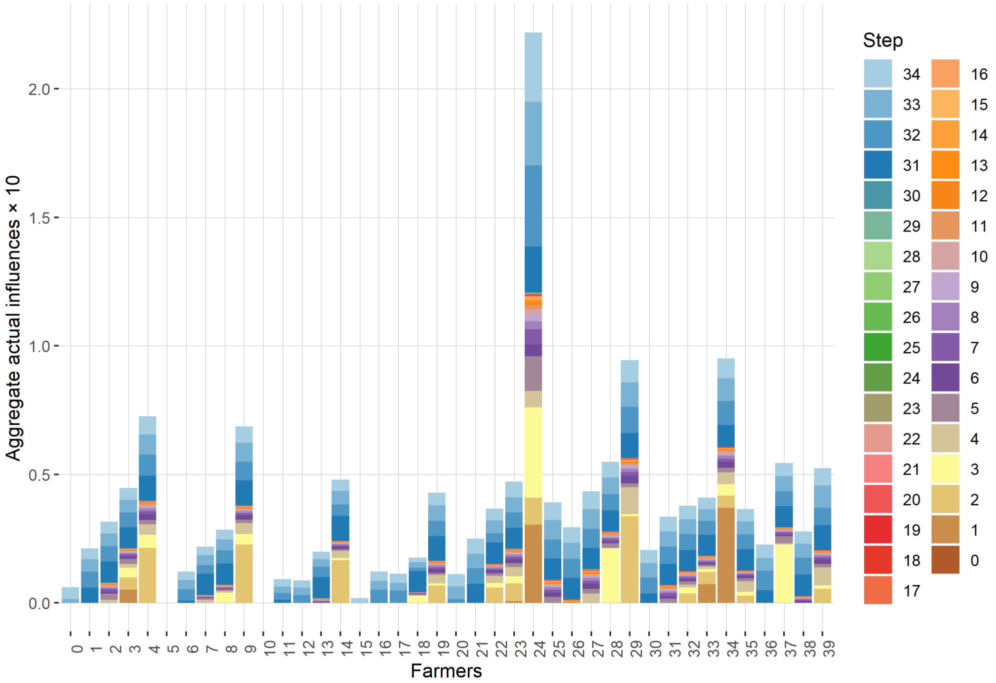


Figure A.9: Aggregate actual influences of farmers multiplied by 10 when farmer 24 has 7 extra connections with other dissatisfied agents

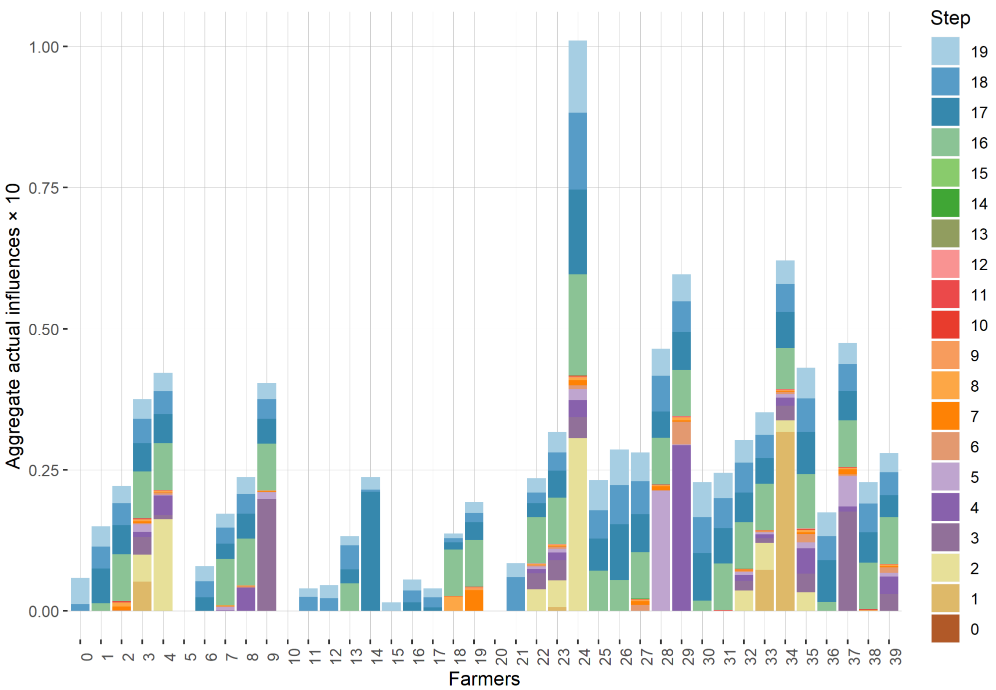


Figure A.10: Aggregate actual influences of farmers multiplied by 10 when farmer 24 has 7 extra connections with mostly satisfied agents

somewhat similar (three extra steps after total water is 40 until reaching consensus).

To check hypothesis 4, which is about existence of prestigious satisfied key individual, different experiments are done. In some of the experiments a prestigious satisfied agent caused the system to reach consensus only when the total water was 35 while in other experiments a satisfied farmer with a higher prestige didn't have much or any negative impact on the eco-

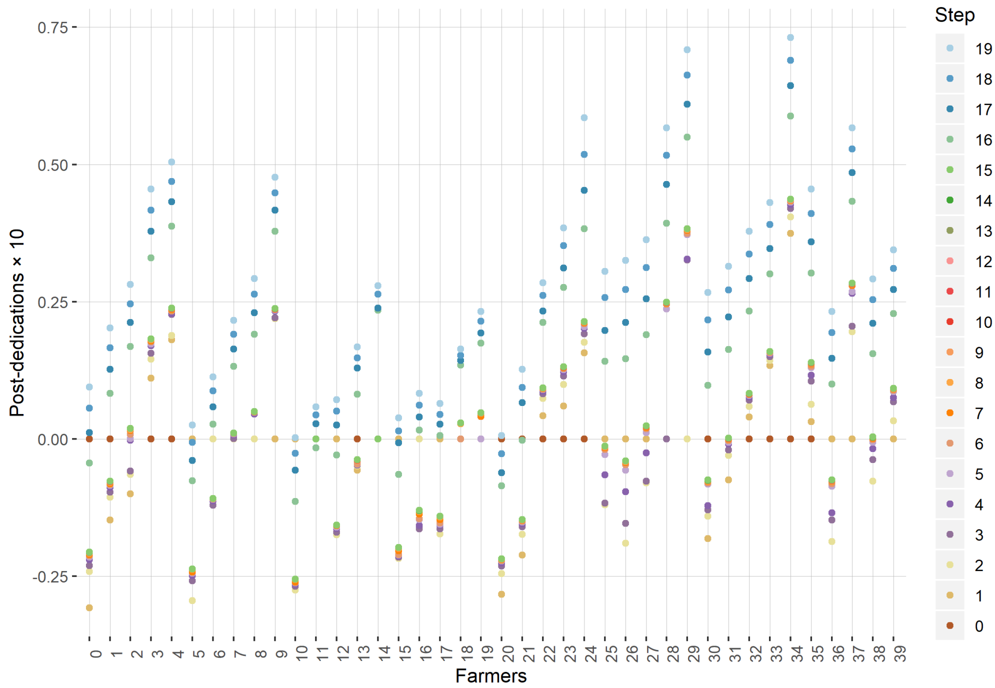


Figure A.11: Post-dedications of farmers multiplied by 10 when farmer 24 has 7 extra connections with mostly satisfied agents

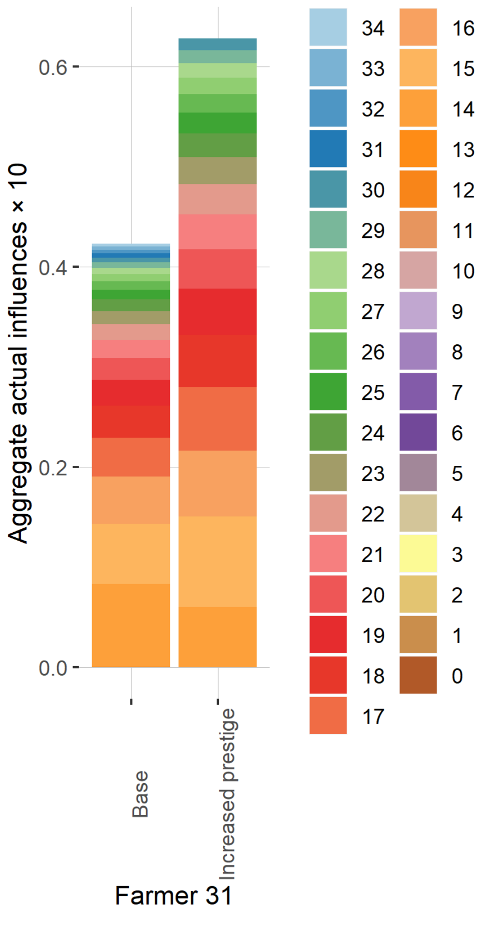
logical pressure or the number of steps needed to reach consensus. There were even cases where the system reached consensus slightly sooner. A deeper look at the reasons behind this behavior showed that the social network plays an important role here. If the satisfied agent is well connected to dissatisfied agents (high number of connections to very dissatisfied farmers) it will become dedicated even though the negative personal conviction of the key individual is stronger due to a higher prestige.

To illuminate, an experiment with farmer 31, which is satisfied, as the key individual with a higher prestige is done. The results can be observed from figure A.12 that despite similar final post-dedication in these two cases, aggregate actual influence of farmer 31 is higher in the increased prestige scenario and consensus is reached 16 steps after reduction of the total water to 40. It took 20 extra steps in the base model scenario. In both scenarios the last water reduction happened in step 14. So it seems even a prestigious satisfied farmer can be helpful for easier adaptation of an idea.

This experiment rejects the fourth hypothesis. Instead, it can be said that the more satisfied an agent is, the more initial exerted influence on the agent should be to make it dedicated towards the idea. When it is dedicated, even if it is satisfied, it will beneficial for achieving consensus. Therefore, a combination of prestige, satisfaction and maximum exerted influence of an agent's connections, before the agent itself is dedicated and is producing a feedback effect, determines if higher prestige is useful or not.

Hypothesis 5 is quite straightforward since it directly affects the personal conviction of agents. A full experiment on all agents proved that increasing preference makes reaching consensus easier while decreasing it has the opposite effect. Hence, this hypothesis is accepted.

The system behavior resulting from increasing farm size of agents is hard to predict and understand due to the block-based system of water distribution. Again, using a full experiment on all agents it was proved that this hypothesis is wrong. When farmers have bigger farms, they also get a bigger share in the water, so in most cases their dissatisfaction will drop in comparison to the base model. This is while in the literature, like the article from Komakech et al. (2012), higher endowment is attributed to higher incentive for participating in and accepting costs of collective action. In terms of this conceptualization, an agent's personal conviction should actually increase with an increase in the farm size. However, this is



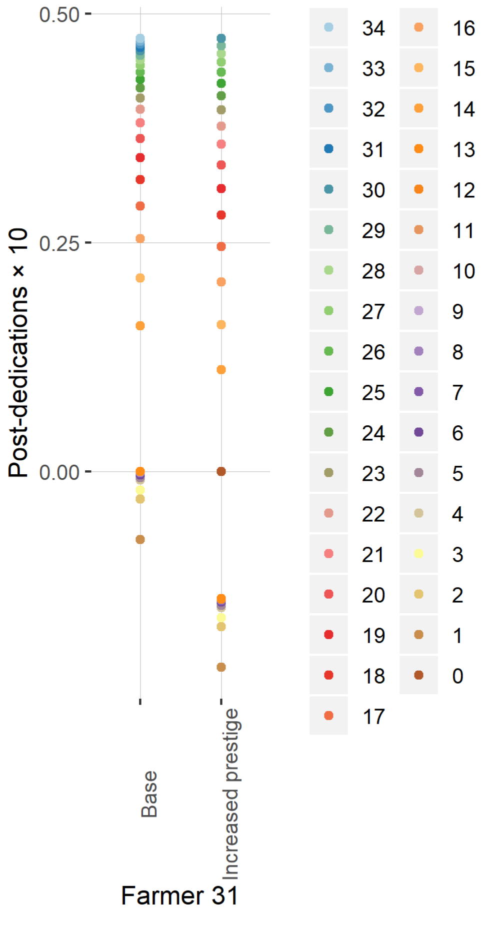


Figure A.12: Comparison of outputs for farmer 31 the in base model scenario and when it has a higher prestige

not the case in the model.

This points out to another serious shortcoming of the model that needs to be addressed in the next step of model. Based on the current conceptualization, an agent will be happier with getting more water, even if the allocated water is more than what the agent needs according to its farm size. Just removing this possibility of satisfaction will not solve this problem since when agents do not have any reason to be satisfied with the current situation, they will simply accept any new idea, again and again! Moreover, regardless of what causes this satisfaction, allowing agents to become satisfied made analyses of previous hypotheses possible. This issue calls for a more complex and complete conceptualization of satisfaction of agents and why they would have incentive to become dedicated to an idea. With this conceptualization it is not possible to analyze effects of endowment more than this, so it will be left for the next step of model.

When satisfied agents have more connections, in all possible scenarios, reaching consensus will become faster, even though *successful elaboration* might happen at a higher ecological pressure (40 instead 45 in the base model). Therefore, hypothesis seven holds true. In short, higher number of connections will help reaching consensus more easily, however, it can hinder elaboration if the idea generator has extra connections with mostly satisfied agents.

Key individuals with higher tie strength, which is the subject of hypothesis 8, proved to make reaching general agreement faster as well, as well as increasing the aggregate actual influences of the key individuals. This hypothesis is accepted as well.

The experiments done for the fifth hypothesis should be enough to reject the ninth one, which claims the intensity of emergent behavior is based on how much satisfied or dissatisfied key individuals are. The social network of each agent plays a very important role next to the personal characteristics and ecological conditions on how they behave in the system.

Different experiments with multiple key individuals show that the model behavior won't be a simple aggregation of model outcomes of scenarios with single key individuals. For example, farmer 20 and farmer 24 from the same branch were chosen to have a higher prestige. If farmer 20 alone is more prestigious, the consensus is possible only if the total water is 35, while a more prestigious farmer 24 will make faster achievement of consensus possible. Nonetheless, the model with both of them as key individuals with higher prestige will result in a faster consensus. It is true that still adding a key individual that stands in the way of general agreement to a scenario where there are key individuals who are helping to reach consensus easier, will have some negative effect, yet, the result won't be a simple summation. That is to say if single key individual A makes reaching consensus x steps faster and single key individual B makes it y steps slower, in the model with both of these key individuals, consensus time will not follow $x - y$ time steps in comparison to the base model.

The final remark about behavior of farmers is that they are boundedly rational. Their personal conviction is partly related to their beliefs and they may become dedicated to the idea even though their personal conviction is against it. Following models depict bounded rationality conceptualization of farmers as well.

A.2. Improved model

In this step of model, five improvements is implemented. First, the dissatisfaction conceptualization is improved. The incentive to increase personal conviction is re-designed to be more realistic and consistent with the literature.

Second, instead of using combination of ecological pressure or the total water and the steps till consensus, a single measure is used as the main key performance indicator of the system. These two are key performance indicators of the whole system.

Next, an indicator for the enabling leadership is conceptualized and realized.

Fourth, another indicator is created to measure the importance or effectiveness of agents' leadership in the system. An agent might exert a lot of influences, however, it is possible that this agent's influence is not critical and if there was no exerted influence by this agent, other agents would have exerted more influence to achieve consensus in a similar ecological pressure. These leadership indicators are the key performance indicators at the agent level.

And last, idea generation is changed as well. In the previous model the agent with the maximum idea generation possibility would have been chosen to create the idea. In that model, there wasn't any problem of having multiple agents which have the maximum idea generation possibility in the system at the same time, but since this happens in some scenarios of the second model, it was decided to choose the agent with the highest number between those which have the highest idea generation possibility. Numbering in the system follows $column \times 5 + row$. Row and column were agents' constant variables which could have been 0 as well.

In what follows the conceptualization of these improvements is explained and some hypotheses are presented, followed by results of experiments done to certify these hypotheses.

Conceptualization

Last improvement introduced is straightforward enough not to require more detailed explanation.

First notion to discuss is the modification of dissatisfaction conceptualization. Two main problems were observed because of the previous conceptualization. First, agents were satisfied with more water even if they couldn't use it because of their limited farm size. The second problem was due to lack of any reason for farmers with bigger farm size to be dedicated to a new idea. Farmers with bigger endowment were even more satisfied because they got more water and utilization rate of their farm did not matter.

To overcome these two problem dissatisfaction was changed in the following way. Each agent can be dissatisfied due to two different reasons, one is because of the amount of allocated water they can utilize, the other is due to the lost potential of their farm size. They are named water dissatisfaction ($WDiss_{a,t}$) and potential dissatisfaction ($PDiss_{a,t}$) respectively.

Agents require a minimum amount of water which is called minimum livelihood required water ($MLRW$). This variable represents the minimum amount of water a farmer needs produce enough for everyday life. Less than this causes dissatisfaction, while having more makes them satisfied, as long as they can actually use the allocated amount of water. Thus, every agent has a variable which represent the usable allocated water ($UAW_{a,t}$) and can be determined using equation A.9.

$$UAW_{a,t} = \min(AW_{a,t}, F_a * RWUF) \tag{A.9}$$

After calculating this value, it is possible to know water dissatisfaction of an agent according to equation A.10 in which water dissatisfaction is limited between -1 and 1.

$$WDiss_{a,t} = \frac{MLRW - UAW_{a,t}}{MLRW} \tag{A.10}$$

Division by the minimum livelihood required water ($MLRW$) in equation A.10 is to normalize the value for all agents. This way, if an agent has no water it will have the maximum dissatisfaction while in case of having twice as much as required it will have maximum satisfaction.

Potential dissatisfaction of an agent is cause by not having enough water to utilize all their farm size. Equation shows the model formalization of this concept. This variable is between 0 and 1. In other words, there is no potential *satisfaction*.

$$PDiss_{a,t} = \frac{RWUF \times F_a - AW_{a,t}}{MPRW} \tag{A.11}$$

In this equation, $MPRW$ is the maximum possible required water and it is a dependent variable that represents the maximum amount of water that an agent with maximum possible farm size can use. Maximum of possible farm size is defined to one in the model conceptualization. Therefore, the maximum possible required water will be equal to required water per unit farm ($RWUF$).

Equation A.11 resembles the formalization of dissatisfaction in the previous model, however, in that formalization dissatisfaction could have been negative (i.e. satisfaction) which was not logical. Having more water than can be used by the farmer should not cause satisfaction. The water satisfaction in the new conceptualization, however, means that an agent is producing more than it needs.

From these two values every agent computes its own dissatisfaction. In most situations, dissatisfaction of an agent is the same as its water dissatisfaction, unless, potential dissatisfaction is more than water dissatisfaction and the agent thinks an unacceptable amount of potential gain is going to waste. This is represented by potential dissatisfaction limit $PDissLim$ as a global variable. Model formalization of dissatisfaction is according to equation A.12.

$$Diss_{a,t} = \begin{cases} PDiss_{a,t} & \text{if } PDiss_{a,t} \geq PDissLim \land PDiss_{a,t} \geq WDiss_{a,t} \\ WDiss_{a,t} & \text{otherwisse} \end{cases} \tag{A.12}$$

The changes in the system key performance indicators are critical for conceptualizations of new agent key performance indicators introduced. While analyzing the experiments for the last model I noticed this shortcoming has led to some difficulty in comparing effectiveness of different key individuals on the system behavior. Therefore, in this model the total water required for reaching consensus is used as the main indicator. To get results that can differentiate between scenarios properly, water reduction in steps that there is no noticeable difference between pre-dedication and post-dedication is changed to 0.01 instead of 5.

To understand the relationship between consensus time and the ecological pressure necessary for reaching consensus some experiments were performed after implementation of changes in agents' dissatisfaction. Figure A.13 presents the ecological pressures of different time steps in the base model scenario of the improved model. The ecological pressure indicator is the difference in the total water of each time step and the initial total water.

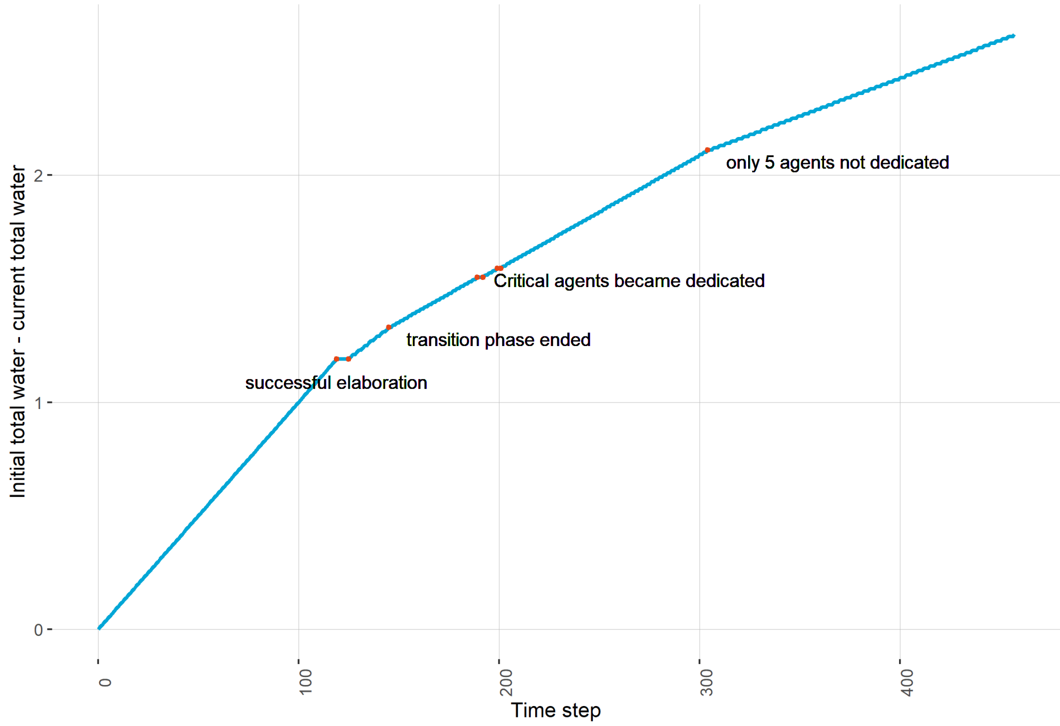


Figure A.13: Ecological pressure change through time in the base model.

In the beginning of each run, at each tick the ecological pressure increases until there is successful elaboration by an agent. Afterwards, some agent become dedicated in the next steps. Influences these newly dedicated agent exert causes the model to continue in the same ecological pressure for some time steps. Four steps after the last agent became dedicated in the same ecological pressure, it start to rise again.

This new period is called transition phase, since the rate alternate between 0.1 ecological pressure rise every step or every two time step. This is finished after a new agent becomes dedicated and rate is stabilized at 0.1 rise of ecological pressure at every two steps. This rate implies that the feedback effect of agents' influence is too small to have a meaningful affect on the system behavior when less than half of agents are dedicated. Twice the ecological pressure increase rate becomes slower when two agents become dedicated in the same time step. The rate finally slows down for good when 35 agent out of 40 become dedicated. After this point enough agents are present to produce enough feedback effect to require a slower rate of ecological pressure increase.

Due to the changes in the rate of the ecological pressure increase that happened after some agents became dedicated, it is evident that the social network and/or agent characteristics affect this rate. To support this conclusion it is necessary to have a proper indicator for the time it takes for the system to reach consensus. This indicator also needs to be comparable between the scenarios. For this purpose, consensus time is defined as the number of time steps that the system needs to reach consensus if it has been under the necessary ecological pressure from the beginning (i.e. when there is no idea or dedication). Its implementation in the model, is done by adding an extra phase after the normal model run is finished. In this extra phase, the initial total water is not changed to keep the necessary ecological pressure however agents' characteristics are set back to default, so there is no dedication or dissatisfaction and agents are not aware of any idea. The time steps that are passed from this point until reaching consensus is called the consensus time.

To sum it up, the ecological pressure necessary for reaching consensus is considered the main system KPI. Consensus time is only used as an auxiliary KPI. It is assumed that in a real social-ecological system to reach a general agreement for collective action, the ecological pressure that can push them to self-organize is more important than the time it takes them to do so.

As discussed before, enabling leaders were identified as visionary and persistent individuals who push the community towards a common goal. In my assumption, these features comes from their personal conviction toward the common goal or the idea. If one wants to answer the question of how much an individual has contributed to and has *enabled* the collective action (consensus is conceptualized as the start of collective action here), one must compare the outcomes with a scenario in which that individual has not shown any personal conviction toward the idea. In fact this conceptualization allows a better understanding of who has *enabled* the collective action and who has *hindered* it. The outcome that should be used for comparison is the necessary ecological pressure for reaching consensus. In this manner, the results are not about who has shouted the loudest any more.

A similar idea is used for conceptualization of effectiveness of the leadership (aggregate actual influences) shown by agents. Effective leadership is about finding how much an agent's leadership has contributed toward reaching the consensus instead of reporting who shouted most. To find this value for an agent for a scenario, the necessary ecological pressure is compared to another scenario in which the only difference is that the agent under analysis doesn't exert any influence at all. Thus, for an agent, both of these two indicator are reported in terms of the added (or reduced in case of hindering agents) ecological pressure necessary to reach consensus in case the agent has no personal conviction or doesn't exert any influence.

While experimenting with the model I observed in many scenarios there are agents whose leadership is important even though they are not enabling leaders in the system. This is understandable because some agents might act similar to a bridge between two separated parts of agents or they have a high prestige and therefore they are powerful at influencing others. Figure A.12 in the previous model's result is one of these cases. In that case a satisfied agent had a higher prestige. I used the metaphor of sound resources for personal conviction in the previous section. Agents either produce or echo the sound of an idea. Some agents are necessary to produce this sound and others necessary to echo and reflect it to reach to everyone. Hence, I chose the name of echoing leadership to refer to this necessary role of agents.

Calculating echoing leadership is dependant on the last two conceptualized indicators and follows the following equation.

$$EcL_a = EfL_a - \max(EnL_a, 0) \tag{A.13}$$

Where:

- EcL_a is the echoing leadership of agent a;
- EfL_a is the effective leadership of agent a;
- And EnL_a is the enabling leadership of agent a. Enabling leadership is the only leadership indicator that might be negative.

Effective leadership is calculated by comparing two similar scenarios in one of which there was no exerted influence by the agent. Enabling leadership was calculated in a similar manner by making personal conviction of the agent zero for one of the scenarios. Exerted influence of an agent is nothing but personal conviction (enabling leadership) and reflection of other exerted influences (echoing leadership). When personal conviction is set to zero for calculation of enabling leadership what remains is only echoing leadership while in computation of effective leadership both of them are removed. Therefore, their difference will be the echoing leadership. Moreover, negative enabling leadership refers to the level of hindrance an agent is causing in the way of reaching the consensus. That's why only the positive value of enabling leadership is used in equation A.13.

Finally it is important to note that the enabling and echoing leaderships defined here, are in fact *effective* enabling leadership and *effective* echoing leadership. As you would see in the results section later, a farmer, such as agent 34, may influence other agents greatly due to its personal conviction, yet because of its position, this influencing and leadership is not much impactful. What I care about in this study, is the effective enabling and echoing leaderships.

In the rest of the document, these two types of leaderships are simply called enabling and echoing leaderships.

Table A.3 shows the new variables that are introduced in this new model conceptualization. The rest stayed the same as table A.1.

Table A.3: New variables used in the model

Name	Type	Owner	Independent?
Potential dissatisfaction limit ($PDissLim$)	Static	Global	Yes
Maximum possible required water ($MPRW$)	Static	Global	No
Water dissatisfaction ($WDiss_{a,t}$)	Dynamic	Agents	No
Potential dissatisfaction ($PDiss_{a,t}$)	Dynamic	Agents	No
Echoing leadership (EcL)	Static	Agents	No
Enabling leadership (EnL)	Static	Agents	No
Effective leadership (EfL)	Static	Agents	No

Desired outputs of the model is changed as well, partly to include the new leadership indicators. Moreover, aggregate actual influences and dedications of agents are not needed per tick and the final value can provide enough information, especially since the reduction of the total water is much more gradual, however, dissatisfaction is reported per tick, mostly just to see agents' initial and final dissatisfaction and how it relate to their leadership indicators. Please note this high number of outputs doesn't mean all of them are reported as a separate plot. It suffices just to explain some. Figure A.14 shows the inputs and the outputs of the second model.

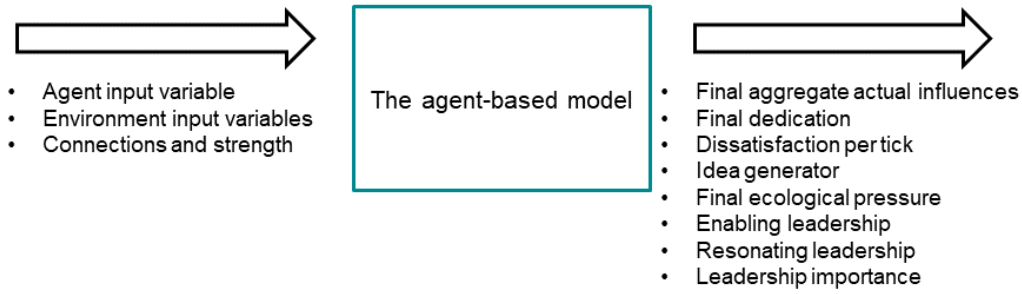


Figure A.14: Inputs and outputs of the second model

Model verification

The concepts that are changed or added need to verified in this step. These are the leadership indicators and dissatisfaction measures.

Starting with dissatisfaction measures, water dissatisfaction was verified first. To verify its implementation, agents' label in the display was changed to show their water dissatisfaction and allocated water. From the previous model's verification phase it was known that the implementation of allocated water is working fine. By using a wide range of the total water from 25 to 0, it was observed that there is no irregular or unwanted result and the water dissatisfaction is implemented correctly. Potential dissatisfaction was confirmed in a similar manner. Satisfaction was verified to follow equation A.12.

In implementation of effective leadership, the agent under study is removed from the list of pre-dedicated agents of each time step. Agents of this list are those who exert influence on others. To verify that the agent under effective leadership analysis is not influencing others, a check was added in the code to control the exerted influence of the agent. It was verified successfully. The implementation enabling leadership is easy to follow and the results are understandable without any irregular behavior. Therefore, its implementation is accepted. Judging based on echoing leadership concept formalization (see equation A.13), it is understandable to say its verification depends on verification of effective leadership and enabling leadership concepts. Since the other two are accepted, the implementation of echoing leadership is taken to be correct. The results from different scenarios support this argument as well. Moreover, since the changes that are implemented in different phases have nothing to do with idea generation and elaboration, the list of idea generator agents should be the same in all these phases for the same model inputs, which was also confirmed.

There are three main phases of the model run. In the phases that are done to find the enabling leadership and the effective leadership of agents, 40 runs (from initial conditions to consensus) are done in each phase. The model input, which creates the initial condition, should be the same for all these. It was verified that during the model run the input provided will remain intact.

Model setup

Considering changes done in conceptualization of dissatisfaction there is a need to change inputs as well, specifically the initial total water and the water loss per step. The weights of factors that are used in the calculation of pre- and post-dedication are changed as well. This changed is done make the effect of agents' dissatisfaction more visible in their dedication. Table A.4 shows the range of values used for the new variables, as well as, new range values for some variables. The rest follow table A.2.

Table A.4: Initial values of new and changed inputs used in the second model

Name	Owner	Base model initial value	Initial values in experiments
Total water	Global	15	15
Water loss per step	Global	0.02	0.02 and 0
Potential dissatisfaction limit	Global	0.15	0.15
η_{EI}	Global	0.33	0.33
η_{PC}	Global	0.66	0.66
Farm	Agents	0.25	[0.2, 0.5]

To understand effects of different key individuals on the final outcome and ease of reaching consensus some hypotheses will be designed and experimented. These hypotheses are as follows.

1. Even in the base model enabling and echoing leaderships can be observed to some extent, due to agents' position and different allocated water.
2. Higher prestige will increase enabling leadership of a dissatisfied agent.
3. If a satisfied agent with a higher prestige is influenced enough by other agents to become dedicated, the agent's echoing leadership indicator will increase.
4. Not only higher tie strength reduces the required ecological pressure, but also it will contribute to leadership indicators (importance, enabling and echoing) of an agent.
5. Higher farm size of an agent can lead to that agent becoming an enabling leader if the agent doesn't have a good position to properly utilize its bigger farm. Good positions are usually at top of branches.
6. Higher number of connections and changes in agents' preferences will have similar outcome as discussed in the previous model's results.

Results

Using the hypotheses mentioned before, some experiments are designed and the results are reported here.

Like the last model I start by presenting and explaining the base model. Figure A.15 presents the aggregate actual influences of agents next to their post-dedication. Agent 34 is the idea generator. In other scenarios that are presented in this sub-section, farmer 34 should be considered idea generator, unless expressed otherwise.

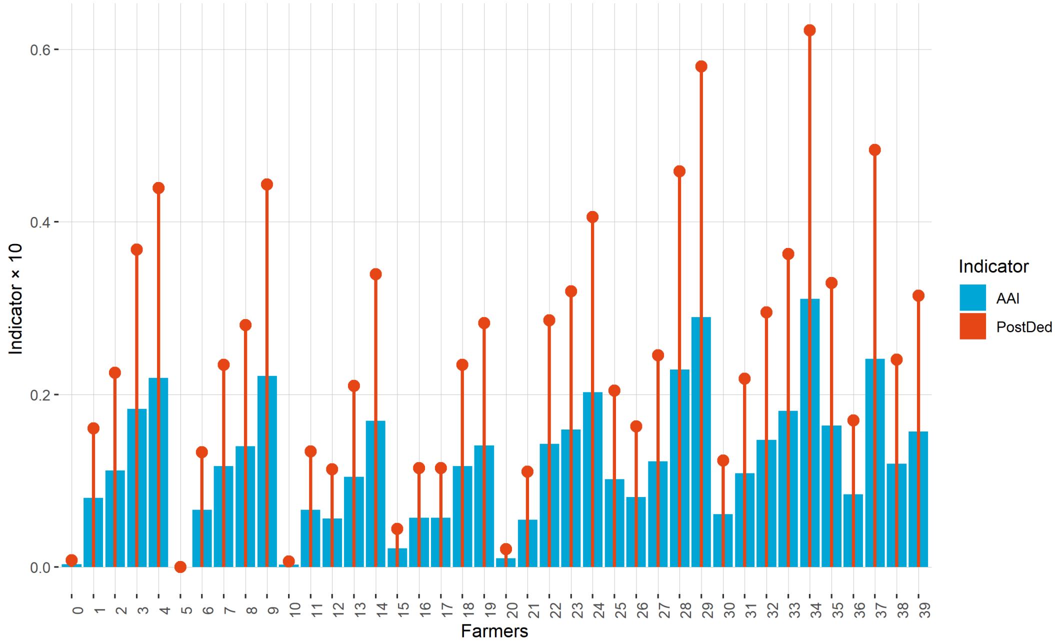


Figure A.15: Aggregate actual influences and post-dedication of agents in the base model

As it can be seen from figure A.16, half of the agents are still satisfied when consensus is reached. By comparing last two figures it is possible to deduce that farmers who are influencing others most, are those who are more dissatisfied and therefore more dedicated. So far, not much difference from the last model. However, considering leadership indicators (see figure A.17), results become very interesting. Some of farmers with the highest aggregate actual influences are not the high on the leadership measures at all!

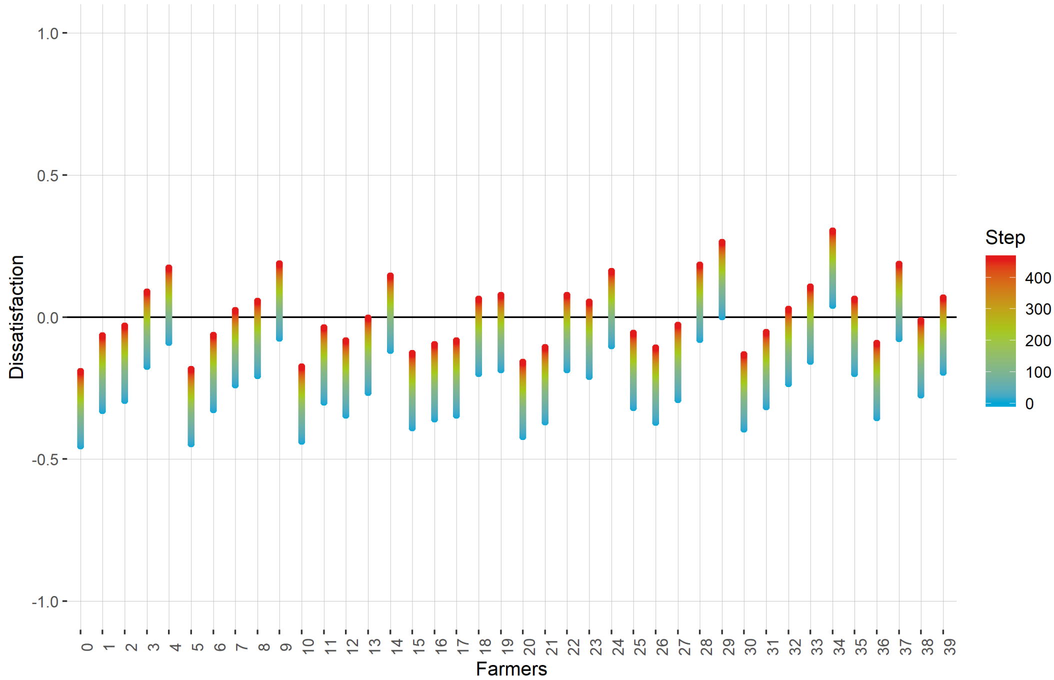


Figure A.16: Dissatisfaction of agents in the base model through out the time steps of normal run

The logic behind this results is that the agents with higher leadership indicators are those

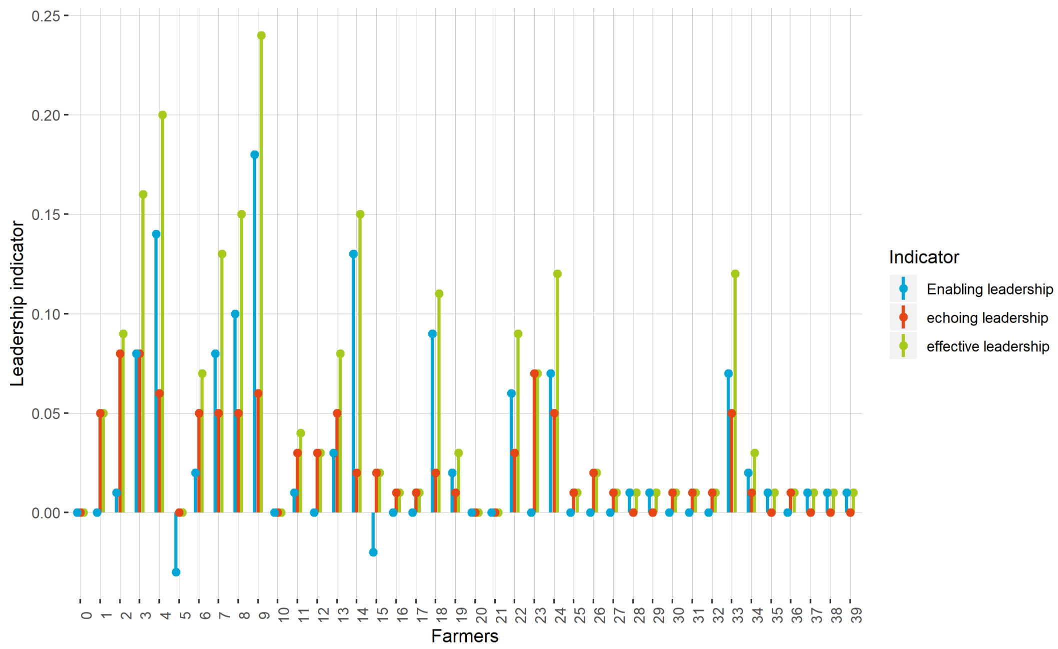


Figure A.17: Leadership indicators of agents in the base model

are connected to most satisfied agents. From the previous model it was known that the network structure is very important, and now it becomes even more clear. In particular, farmer 5, which is connected to farmer 6 to 9, is a barrier in the way of reaching consensus (negative enabling leadership), therefore, this farmer's connections' effort to persuade it becomes critical. In the base model farmers are homogeneous agents that only differ in their access of water, however, the leadership indicators of agent 9 is comparable with the leadership indicators of an agent which is dissatisfied, prestigious (i.e. has a higher prestige than average agents) and has more connections (see figure A.35). The first two branch (columns, farmer 0 to 9) are more important since the most satisfied agents are in top of these branches.

It is good to explain a bit about the reason why I've chosen these types of plots to represent each value. For an agent, aggregate actual influences are accumulation of changes in its connections' dedication, thus, a bar plot can imply this accumulation of actual influences of an agent. Dissatisfaction is calculated and reported in each step, regardless of its value in other ticks. Therefore, I chose to show it using points, however, since the number of time steps required to reach consensus is very high, it seems like a line. Leadership indicators, on the other hand, are computed once in the end of their own sub-scenarios. They are plotted in a lollipop graph to convey they are one-time calculation while it is easy to compare them together at the same time. Post-dedication is another indicator that is computed in each tick, however, because only its final value matters (this decision was explained before) I followed the same logic for them. Leadership indicators are all expressed in terms of change in ecological pressure (the total water in the system) necessary for reaching consensus and it is important to compare them. That's why they are plotted together. Aggregate actual influences and dedication directly affect each other, so, it is fitting to show them in one plot.

The first hypothesis is confirmed based on these results, still it is valuable to see the model behavior if they don't even differ in their allocated water. To make them have the same allocated water, water loss per step is set to zero. As expected, there is no enabling or echoing leadership and no one was a barrier in reaching consensus, because everyone had the same dissatisfaction. This means, there is no enabling or echoing leadership if agents are homogeneous and they have the same utility gain in terms of allocated water. In other words, effective leadership can emerge only if there is at least one factor that differentiate between agents.

Before going further with the experiments done for the hypotheses, I want to present the new leadership indicators that emerge in the base model if the dissatisfaction or weight of factors for exerted influence and personal conviction in the calculation of dedication is not changed.

In a model where mentioned weights of factors are the same as the previous model, that is, the exerted influence is more important than the personal conviction for finding the dedication, consensus time increases, however the ecological pressure necessary for consensus is reduced. This means dissatisfaction of agents become less. Final values of post dedication and the aggregate actual influences become closer as well.

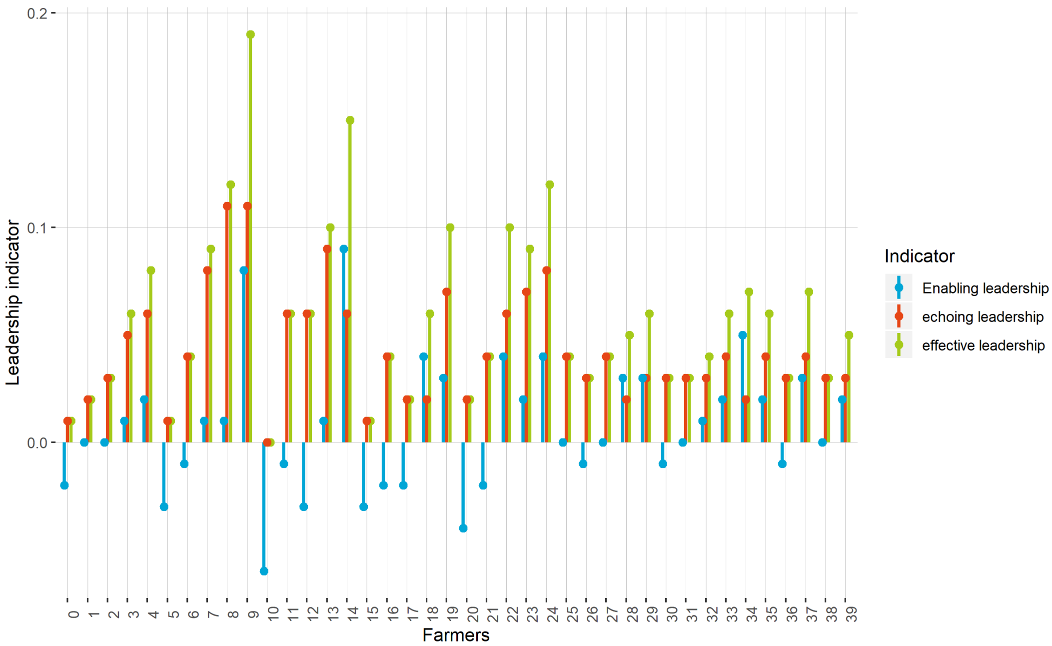


Figure A.18: Leadership indicators of agents in the base model if the weights of factors was the same as the simple model

Figure A.18 presents the leadership indicators in this case. Comparing to figure A.17, it can be seen the there are more agents with negative enabling leadership since the dissatisfaction is lower (and satisfied agents are happier). The lower dissatisfaction combined with the higher affect of exerted influences on dedications of agents means all agents' contribution to create general agreement is more valuable and hence their score on enabling leadership is intensified. However agents who had higher enabling leadership score themselves are exceptions in this statement. Farmer nine and four had high enabling leadership because of their position and not their high personal conviction. Now, even if they are not personally convicted other agents will influence them to become dedicated and contribute toward reaching consensus and hence a higher echoing leadership can be seen. It seems the bigger the affect of exerted influences in calculation of the dedication, the closer the enabling leadership will be to agents dissatisfaction. More on this is discussed in the sensitivity analysis section.

For the previous conceptualization of dissatisfaction it is necessary to set the initial total water and water loss per step to the values used in the simple model. When leadership indicators were checked for the base model with the previous conceptualization of dissatisfaction, the patterns were similar to the results from the new conceptualization, which was expected. Look at figures A.19 and A.20 and their similarities to figures A.18 and A.17 (notice the difference in the Y axis limits).

The impact of dissatisfaction conceptualization modification becomes apparent when an agent's farm size is changed. In the simple model such key individuals are very satisfied and a hindrance in the way of reaching consensus (negative enabling leadership) while in the improved model the behavior is completely different. This is elaborated more in results of experiments done for the relevant hypothesis.

Figures A.21 and A.22 are from the experiment that is done to check the second hypoth-

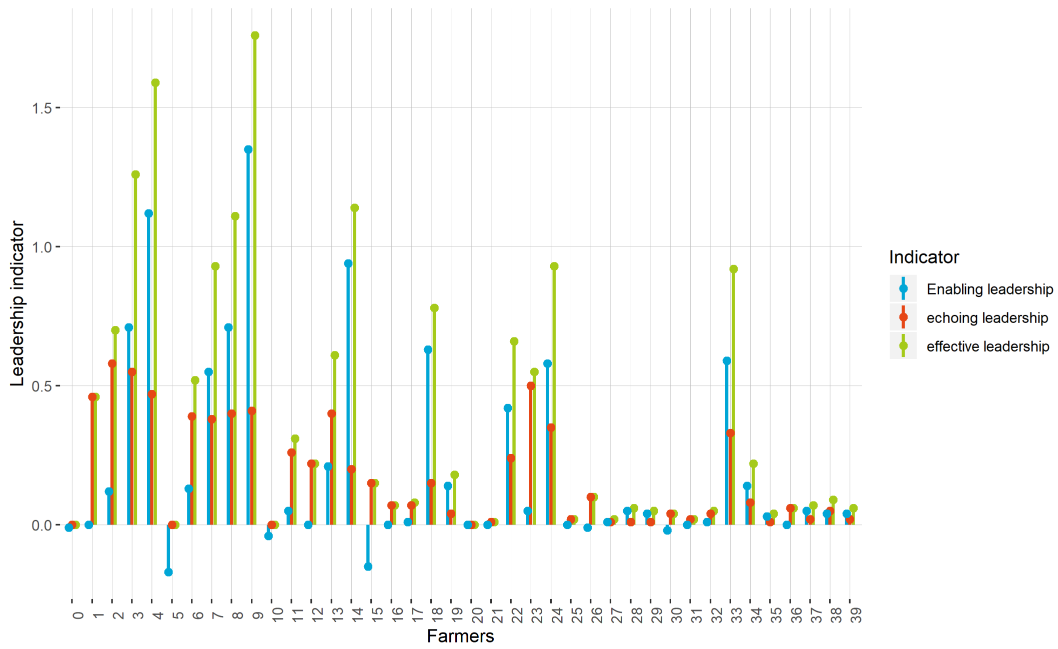


Figure A.19: Leadership indicators of agents in the base scenario of the simple model if the weights of factors were the same as the improved model

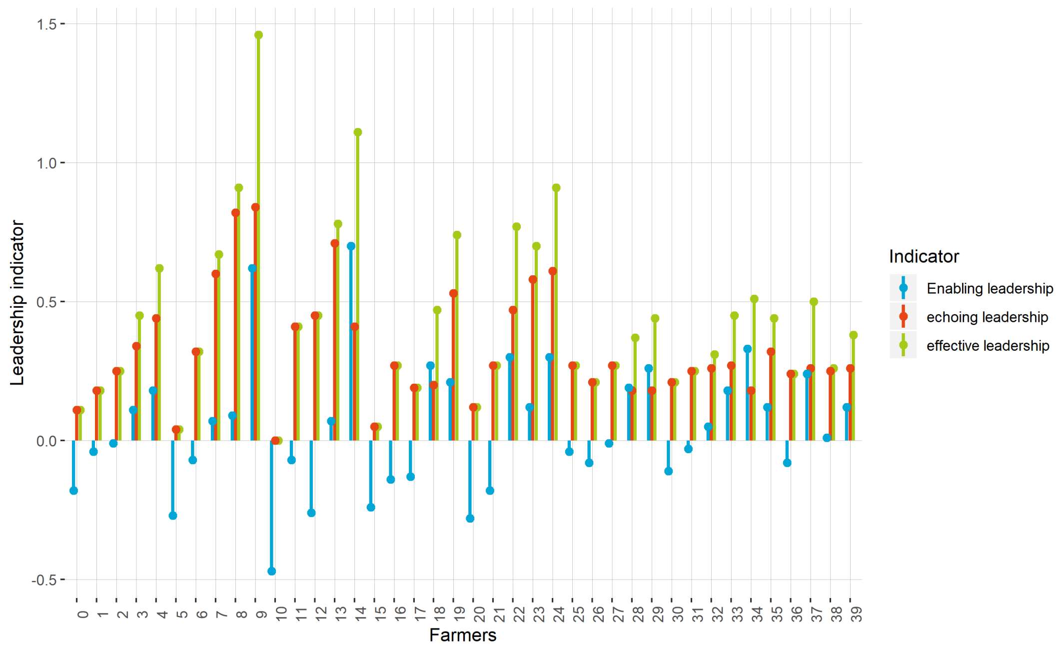


Figure A.20: Leadership indicators of agents in the base scenario of the simple model

esis.

Prestigious farmer 34 is obviously more dedicated than others and has had more influence in the system, yet despite an increase in its echoing leadership, the enabling leadership index has actually fallen! Effective leadership, that is the sum of other two leadership indicators has stayed the same. Effectiveness of other agents' leadership has decreased as well. The ecological pressure necessary to reach consensus is the same as the base model, however the consensus time is decreased from 9 to 7. It might be shocking at first look, it should not be that surprising. Having a more prestigious agent preaching for the idea may have

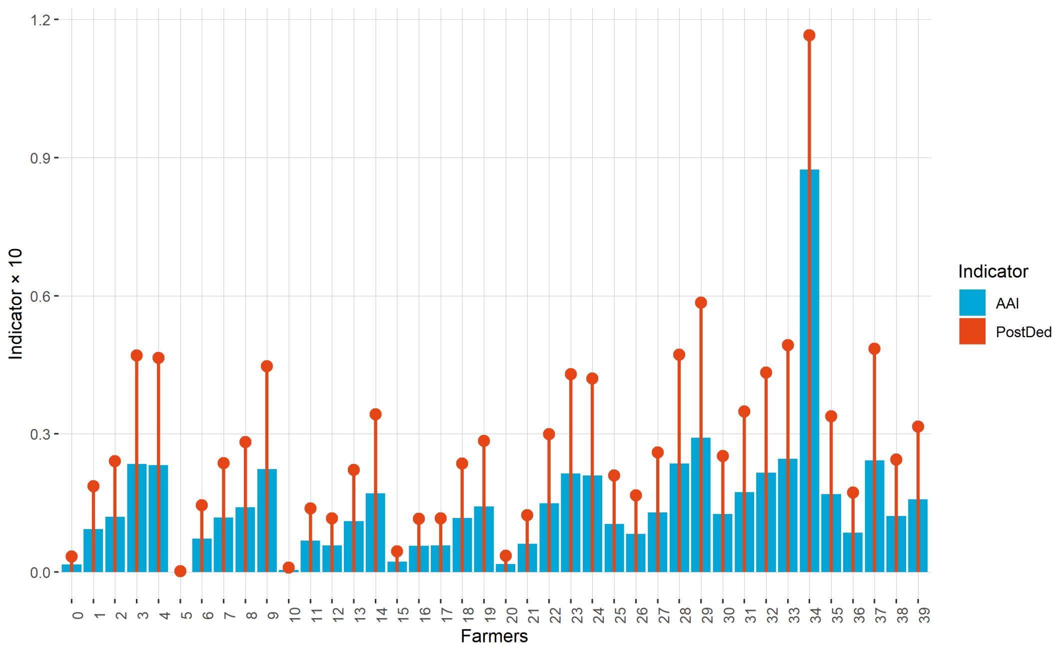


Figure A.21: Aggregate actual influences and post-dedication of agents in the scenario where agent 34 has higher prestige

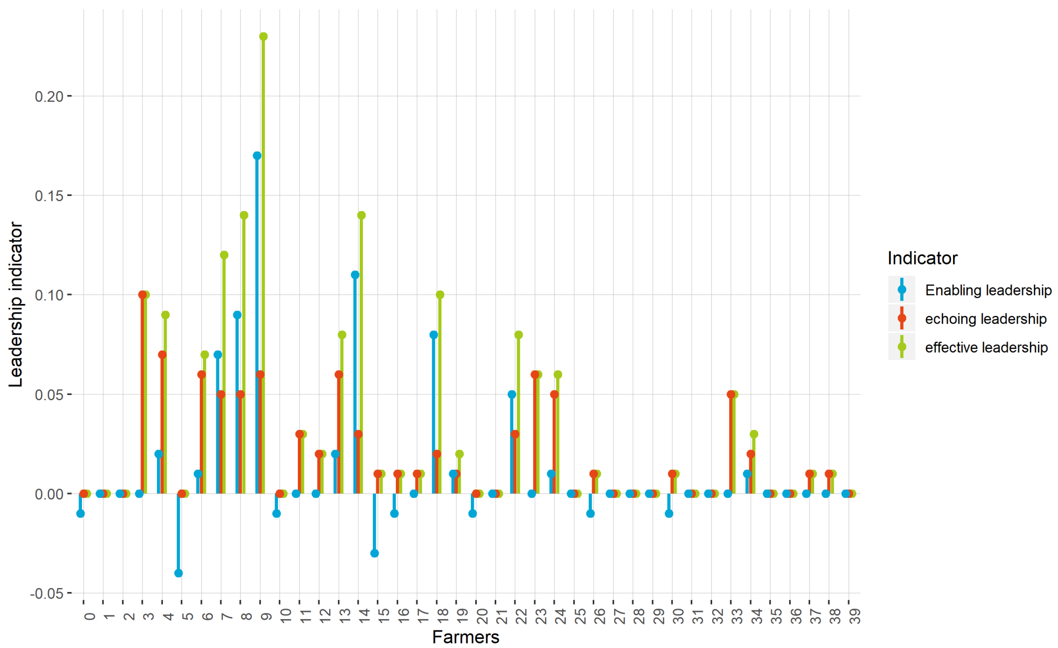


Figure A.22: Leadership indicators of agents in the scenario where agent 34 has higher prestige

decrease the importance of other agents like farmer 9, nonetheless, its position is hampering its effectiveness. Performing an experiment with farmer 9 as the prestigious key individual revealed more.

When farmer 9 has more prestige reaching consensus becomes easier (0.03 higher total water). Farmer nine's enabling leadership stayed the same while its echoing leadership increased (0.03 total water change). It seems considering an agent's position in the social network and its dissatisfaction, giving the agent a higher prestige might decrease it enabling leadership or keep at the same level while echoing leadership increases. Enabling leadership decreases since other agents who are connected to the key individual with higher prestige,

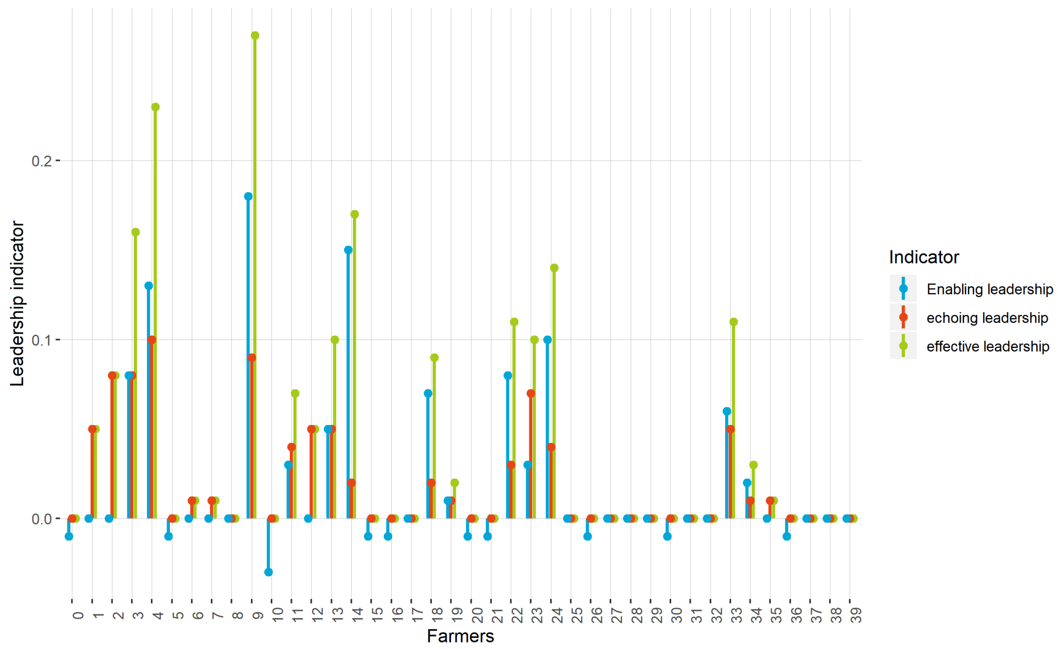


Figure A.23: Leadership indicators of agents in the scenario where agent 9 has higher prestige

can utilize this potential by influencing it. This is the reason why the echoing leadership increases as well. To prove this conclusion I did another experiment in which agent 28 who has similar dissatisfaction to agent 9 was given higher prestige. In that experiment none of this farmer's leadership indicator changed.

Another interesting behavior that emerged from the experiment with farmer 9 as the prestigious key individual is the increase in agent four's echoing leadership. This agent is directly influenced by the prestigious key individual (farmer 9) and thus its influence on satisfied agents like farmer 0 becomes more important. At the same time farmer four's enabling leadership has decreased because farmer 9 is shouldering the burden.

A prestigious farmer 34 is actually contributing to easier achievement of consensus but not enough! A sign of this statement is that in figure A.22 the number of agents who have negative enabling leadership is increased and the effective leadership of others is decreased, as well as the reduction in the consensus time.

All in all, higher prestige contributes to the effective and echoing leadership, however, the agent's position in the social network and dissatisfaction also affect how these leadership indicators change. Moreover, this prestigious key individual contributes to reducing the necessary ecological pressure, the consensus time and the expected leadership of most of other agents (all indicators) if the necessary ecological pressure is staying the same, otherwise because of the lower ecological pressure the leadership indicators will generally escalate (in both positive and negative directions). Therefore the second hypothesis is not right and other factors should be looked into as well.

The third hypothesis is inspired by one of the experiments of the first model in which, farmer 21, a satisfied agent, was given higher prestige. Different experiments proved this hypothesis is wrong despite the increase in the key individual's aggregate actual influences in comparison to the base model. Farmer twenty ones leadership indicators are all zero and there is no reduction in the consensus time or the necessary ecological pressure. If a very satisfied farmer, like farmer 5 is chosen to have higher prestige, the necessary ecological pressure will increase. Interestingly, the consensus time decreased. A look at figure A.24, show that farmer 5 is a serious barrier for a general agreement in this case.

Low enabling leadership of many agents, as well as the lower consensus time, are a consequence of very high ecological pressure. In other words, considering general unhappiness about the conditions, there are many farmers advocating for the change, and therefore, a

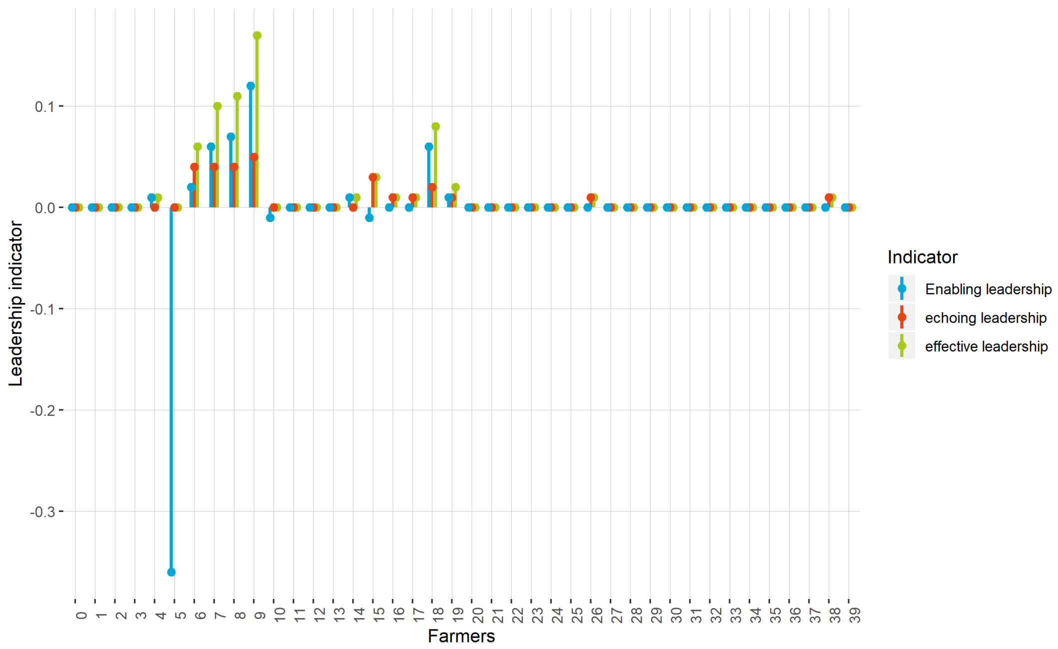


Figure A.24: Leadership indicators of agents in the scenario where agent 5, a very satisfied farmer, has higher prestige

single farmer's influences become less important. Note that the agent level KPIs designed here are focused on impacts of a single farmer, not a group of them. Another experiment was done in which 7 agents on top of branches (out of 8) who were satisfied were given higher prestige. In this experiment, ecological pressure at the time of consensus was the same as when only agent 5 had higher prestige. It shows that at such high ecological pressure change seems inevitable. Of course, in real world, if there is not enough social capital, this might lead to unsolvable conflicts.

Hypothesis 4 is about the effects of increasing tie strength. Depending on the the farmer that is chosen to be the key individual it may lead to a decrease in the required ecological pressure for reaching consensus. Because of similarity of the this behavior to scenarios with higher prestige, it could have been expected. The effects of increasing tie strength on the leadership indicators, on the other hand, is somewhat surprising. See figures A.25 and A.26.

Farmer nine's enabling leadership has slightly decreased while its the echoing leadership has increase enough to result in a positive change in the effective leadership indicator in comparison to the base model. When the agent has stronger connections it will be easier to be influenced as well. So even if its personal conviction is zero, other dissatisfied agents connected to it will compensate the lost conviction to some extent. That is why the echoing leadership becomes more important as well. One of these connected agents is farmer 4, which has somewhat similar dissatisfaction. It is interesting to see that farmer four's enabling and echoing leadership indicators have slightly increased. It can be understood that an increase in tie strength of agent 9 has led to a distribution of responsibility, for example with agent 4. Of course, the full interactions are more complicated than this and agents influence each other through other agents in between. Yet, other agents which are in the same branch as agent 9 are reporting lower values for leadership indicators, similar to the experiment in which farmer 9 had a higher prestige. The difference is that farmer 9 doesn't have a connection to persuade a satisfied farmer like farmer 0 and that's where agent 4 becomes critical, since it is connected to farmer 0.

From observing last two figures, it is understood that aggregate actual influence is not closely related to leadership indicators and possibly they can be dropped from the model outcomes for later use.

Another experiment was performed with agent 4 as the key individual with stronger ties.

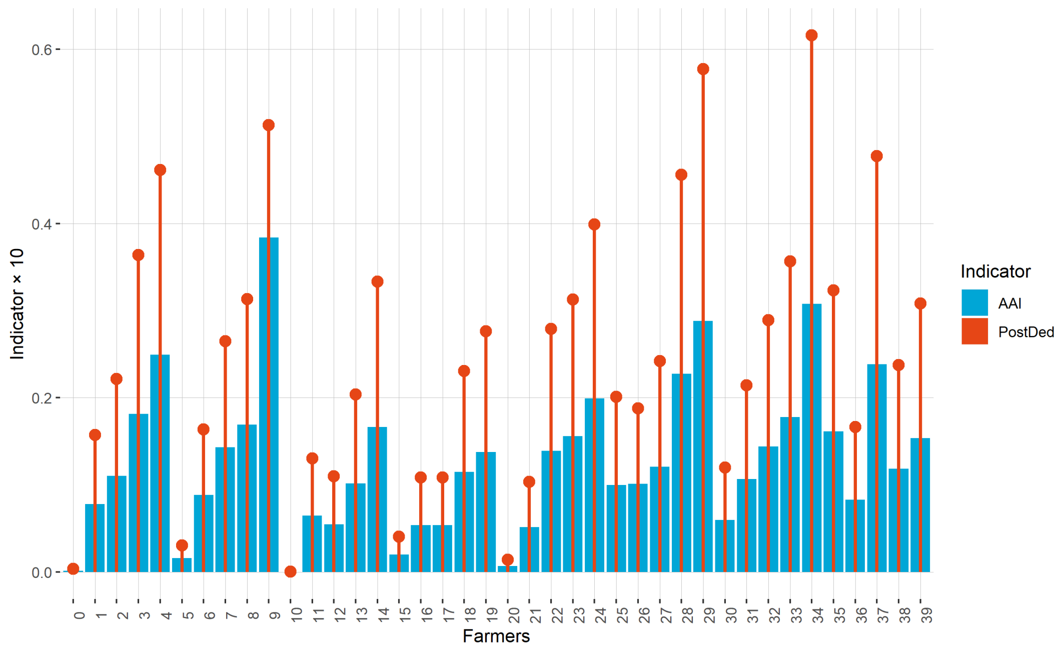


Figure A.25: Aggregate actual influences and post-dedication of agents in the scenario where agent 9 has stronger ties

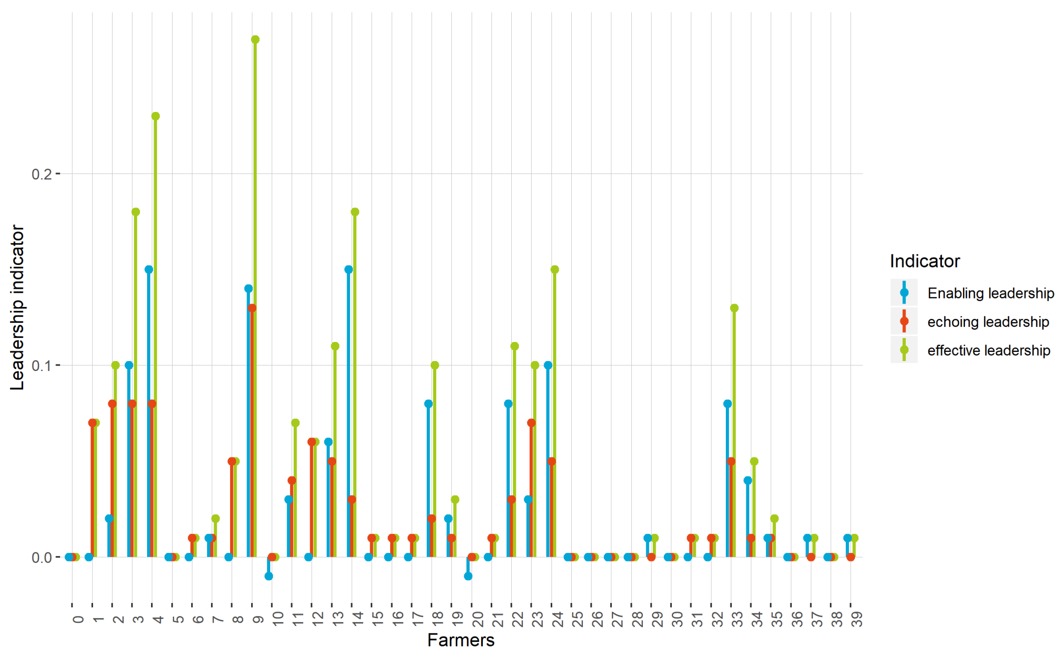


Figure A.26: Leadership indicators of agents in the scenario where agent 9 has stronger ties

In this experiment, the required ecological pressure for consensus was marginally decreased. Similar to the last experiment, enabling leadership of the key individual decreased and its echoing leadership increased. These are reported in figure A.27. Agents of the second branch (farmers 5 to 9) except for farmer 9 have lower enabling leadership indicators as well, while farmer 9 has the same. Almost all of agents in the second branch have higher echoing leadership.

Same logic from the last experiment can be applied here. If farmer 4 is not personally convicted other agents will influence it through its stronger connections to compensate for this loss of conviction. If farmer 9, on the other hand, was not personally convicted to the

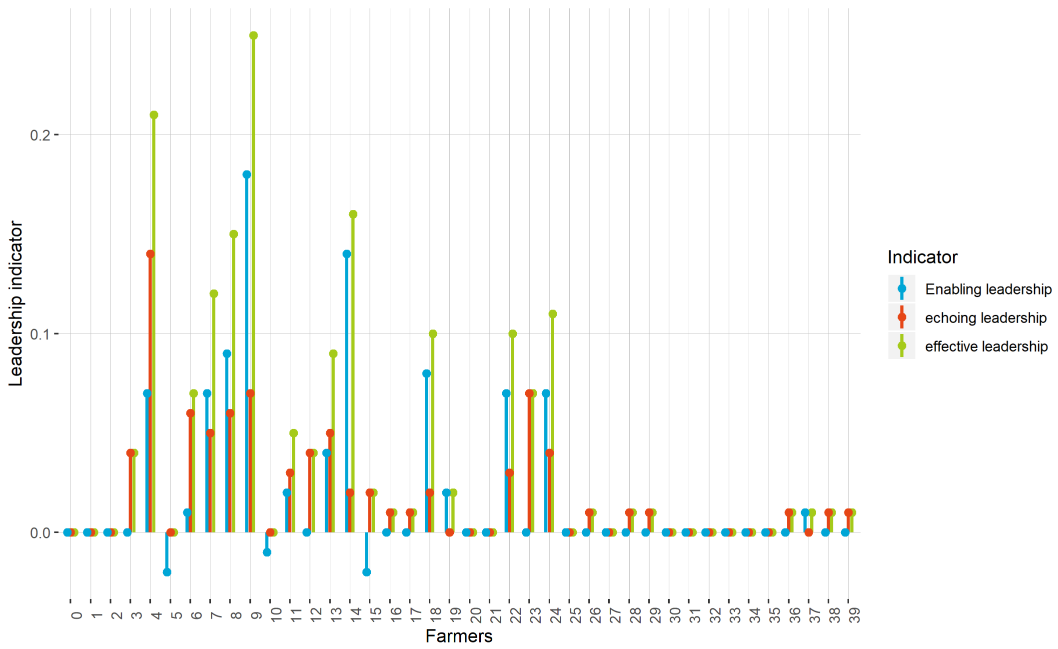


Figure A.27: Leadership indicators of agents in the scenario where agent 4 has stronger ties

idea, even the stronger connection to farmer 4 wouldn't be enough to fill up its critical responsibility. This critical role can be easily seen from the base model.

Next experiment for this hypothesis is when a very satisfied agent, like farmer 5 who is in the same branch as farmer 9, has strong connections. See figure A.28.

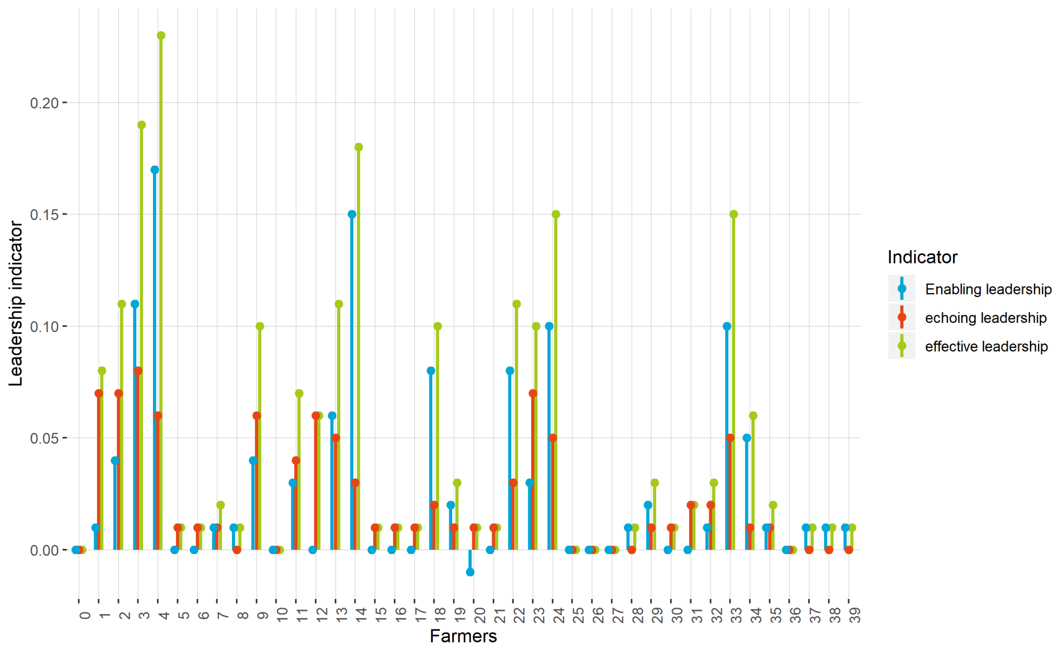


Figure A.28: Leadership indicators of agents in the scenario where agent 5 has stronger ties

When the satisfied farmer five is strongly connected to other agents of its branch, their critical role becomes less important and the necessary ecological pressure is reduced. At the same time, since ecological pressure is less, agents are less personally convicted and therefore, their influence becomes more critical to the extent that even farmer 1, which is satisfied, has a positive enabling leadership indicator.

For hypothesis four, many experiment were performed to inspect the final behavior of the model when a farmer has a bigger farm. It was observed that necessary ecological pressure always and the consensus time most of the times decreases when there is an agent with bigger endowment, no matter if the agent was dissatisfied or satisfied in the base model and its position in the ecological network. In these cases, the reduction in the necessary ecological pressure for reaching consensus is bigger than the changes in the experiments done for the past hypotheses.

In all cases, the agent with the bigger farm is dissatisfied due to its potential dissatisfaction at the time of reaching consensus. The water dissatisfaction of such agents are always negative in the model run until reaching consensus, since they can get enough water for their minimum livelihood. In some cases the agent with the bigger farm actually becomes the idea generator.

Comparison of these results to the base model can be misleading, because water distribution and as a consequence agents' dissatisfaction is changed. Therefore, although it is possible to compare system level KPIs, understanding KPIs at agent level requires independent analysis. Two different experiment are done, in one of them an agent from end of a far branch (high row and column) and in the other one an agent from beginning of a branch near the source (low row and column) is chosen.

Farmer 33 is chosen for the first experiment of this hypothesis. In the case farmer 33 has more endowment, the necessary ecological pressure is 0.21 less (in terms of total water) and consensus can be reached one step sooner in comparison to the base model. It is the idea generator as well. Figures A.29, A.30 and A.31 show the results of this experiment.

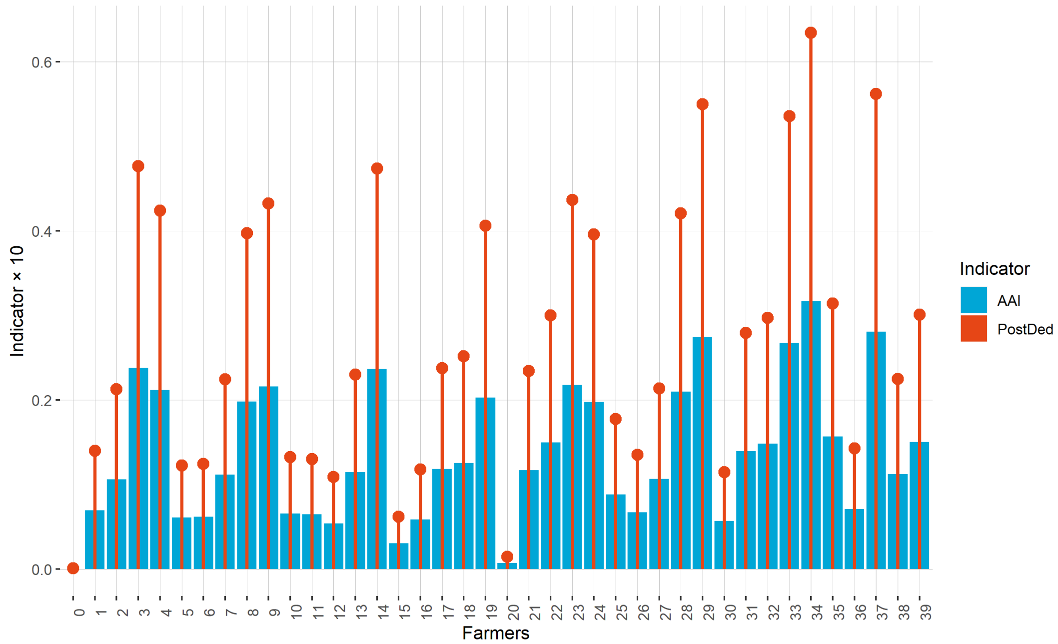


Figure A.29: Aggregate actual influences (AAI) and post-dedication (PD) of agents in the scenario where agent 33 has a bigger farm (0.5)

Notice the different range of dissatisfaction of farmer 33 versus other agents in figure A.30. As it can be seen from here the rate by which potential dissatisfaction increases by reduction of total water is less than the same rate for water dissatisfaction.

Farmer 33 has lower or similar post-dedication to some other farmers, but as can be expected by now, the leadership indicators does not follow the same pattern. Figure A.29 provide this insight that farmer 20 and farmer 0 were the last agents to become dedicated. Farmer 33 is among those who are connected to agent zero (who is the biggest barrier for reaching consensus) and therefore it scores high on effective leadership. In this experiment

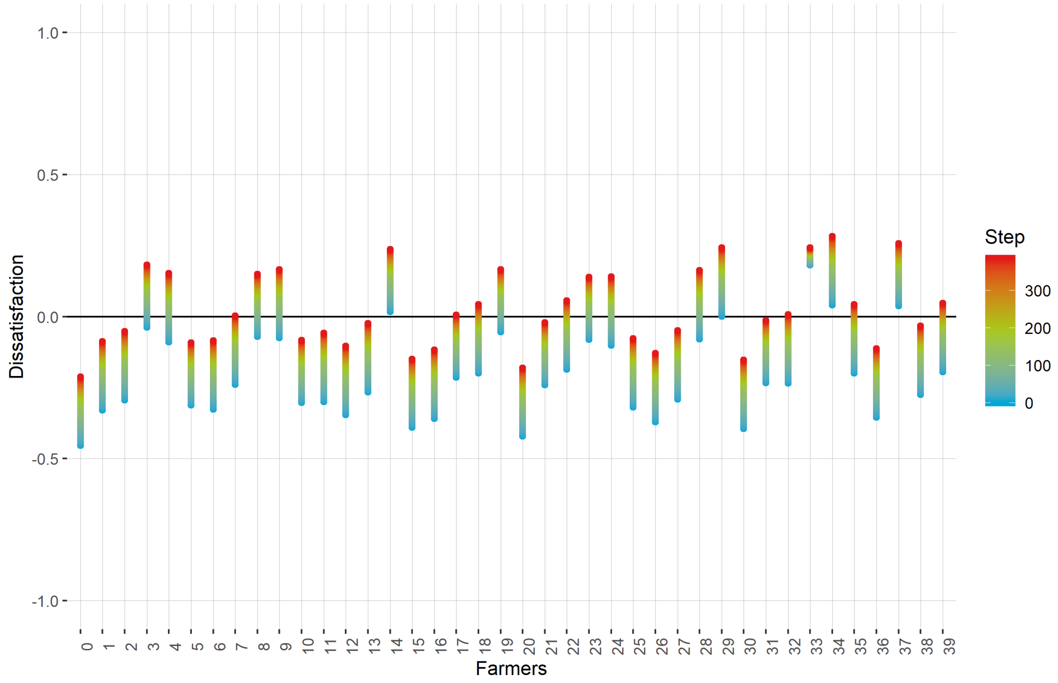


Figure A.30: Dissatisfaction of agents in the scenario where agent 33 has a bigger farm (0.5)

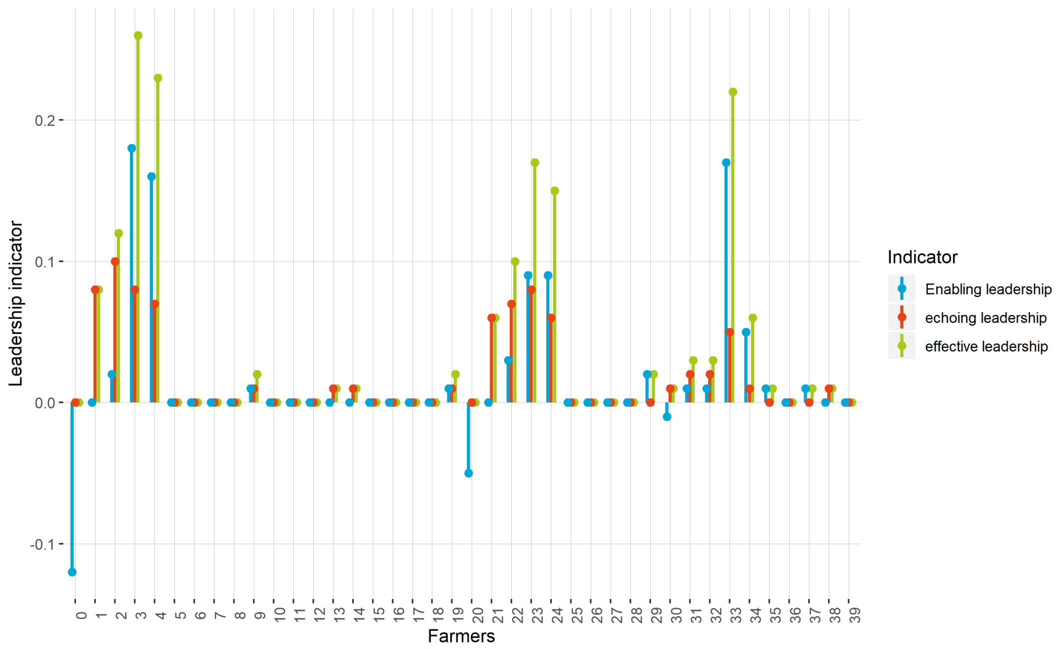


Figure A.31: Leadership indicators of agents in the scenario where agent 33 has a bigger farm (0.5)

agent 33 is a farmer with a big farm and receives enough water, nonetheless, it is among top three effective and enabler leaders of the system.

Figures A.32 and A.33 show the result for the experiment in which farmer 5, an agent on top of the second branch, has bigger farm size. Agent 5 is also the creator of the idea which became agreed upon. There was another idea generator before farmer five, which didn't succeeded in elaboration of the idea and the idea got forgotten.

It is interesting to see in figure A.32 how farmer five's dissatisfaction is separated to this section. This is because in the beginning its dissatisfaction was calculated based on the water

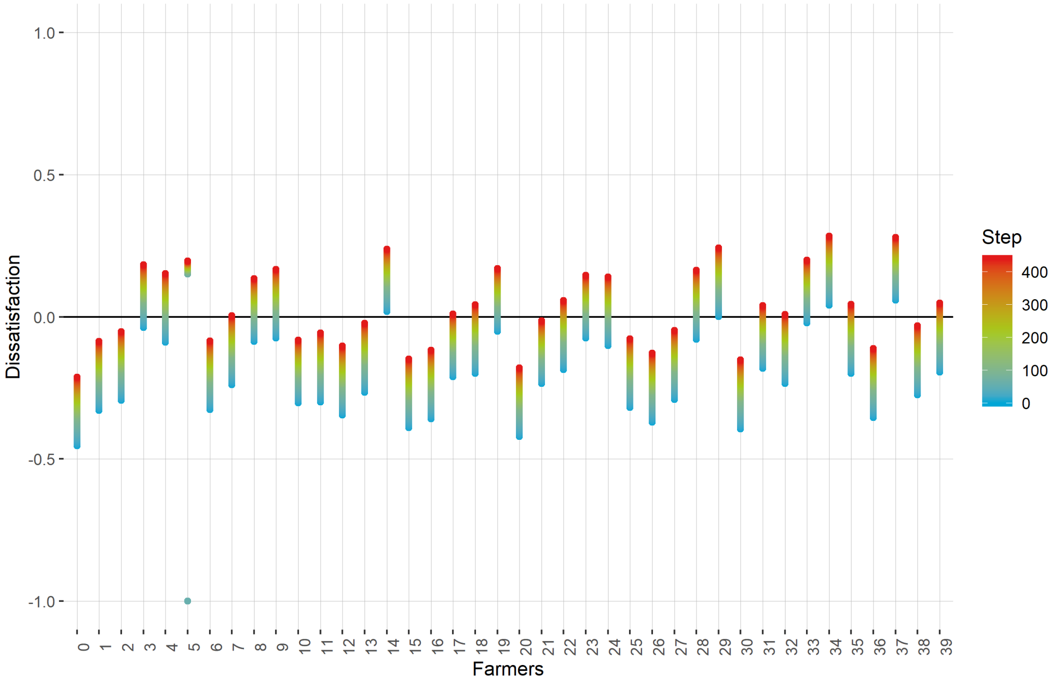


Figure A.32: Dissatisfaction of agents in the scenario where agent 5 has a bigger farm (0.5)

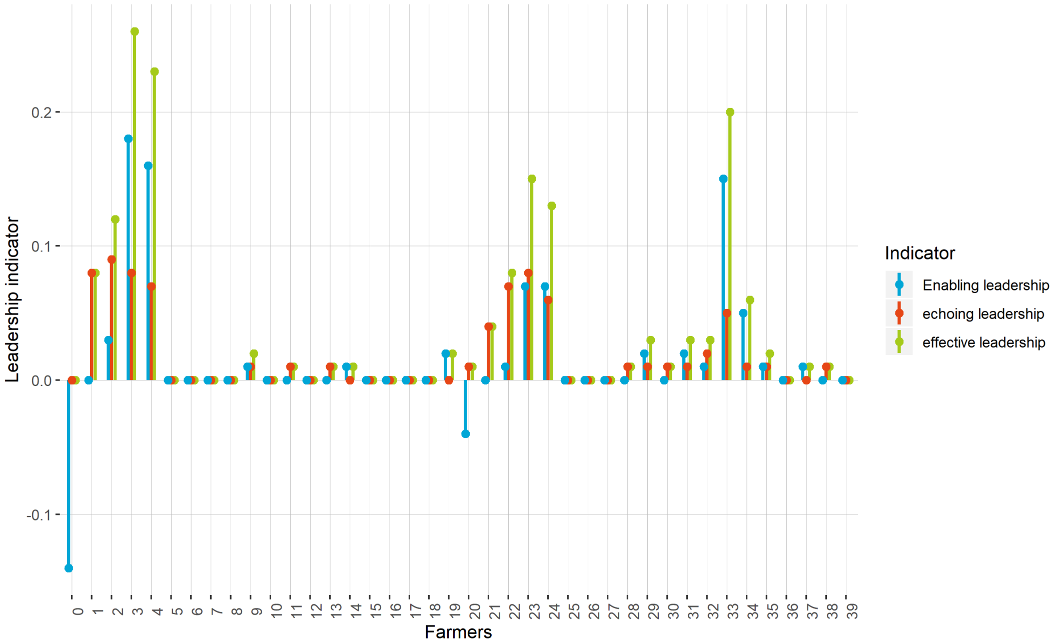


Figure A.33: Leadership indicators of agents in the scenario where agent 5 has a bigger farm (0.5)

dissatisfaction but as the ecological pressure became more, despite full water satisfaction, since the potential dissatisfaction about the utility loss becomes above the limit the agent becomes dissatisfied.

At the end of model run, there is only one agent in the second branch who is satisfied. It is a good time to remind the reader that all agents in one branch are connected. Therefore, it shouldn't be a surprise that these agents, except for farmer 9, are not showing any enabling or echoing leadership. Farmer 9 is connected to farmer 26 which is among the most satisfied agents, so it is understandable that this agent is showing enabling and echoing leaderships.

In conclusion, it is possible to say having an agent with a bigger farm contributes to easier (lower consensus time and lower necessary ecological pressure) achievement of consensus, however, for it to be accompanied by leadership indicator depends on the social network and conditions of other agents.

Last hypothesis checked here is about the impact key individuals with higher number of connections might have. From the analysis of simple model's result it was observed that higher number of connections make reaching consensus easier, however, it might hinder elaboration if the idea generator is connected to mostly satisfied agents.

By now, it has became completely clear that the social network of farmers plays the most important role on who becomes an effecting, echoing or enabling leader. Adding connections directly impacts this factor, so, it was rightfully expected the effects here will be more prominent than any other change that has been done before.

Adding new connections to any agent makes reaching consensus possible at a lower ecological pressure and most of the times, with a shorter consensus time. It is understandable that when the ecological pressure is lower more feedback effect and therefore, more time is needed until consensus.

Regarding agent-level KPIs, always an increase in echoing leadership can be observed even in the case of a satisfied agent with higher number of connections.

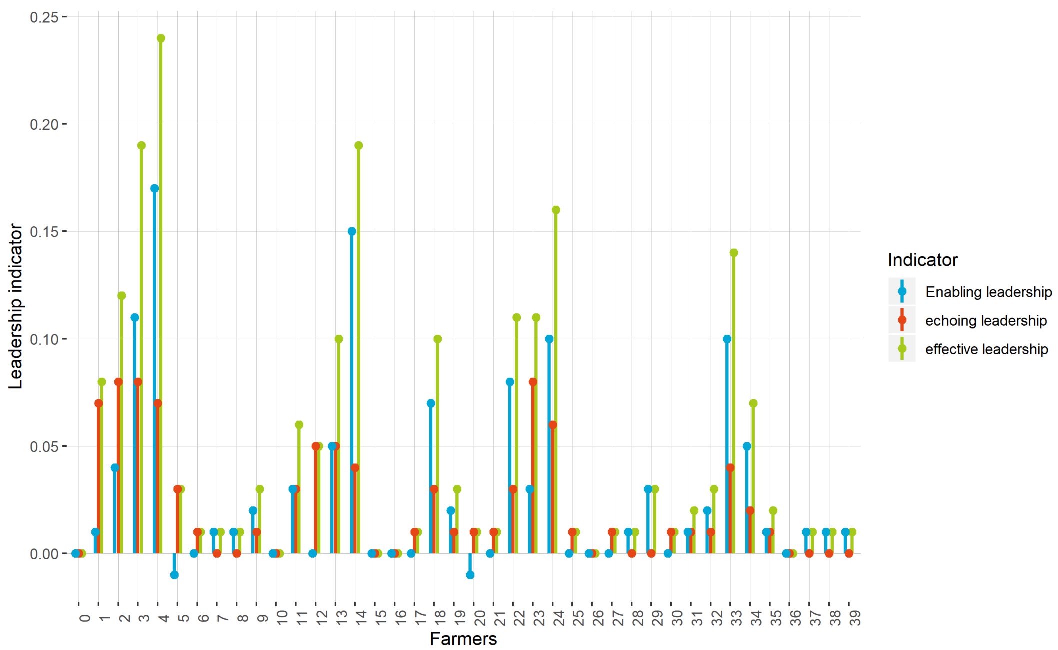


Figure A.34: Leadership indicators of agents in the scenario where farmer 5, which is satisfied, has higher connections to dissatisfied farmers

Look at figure A.34 as an example. Here it can be seen the importance of farmer nine's role is reduced since other dissatisfied farmers are also influencing farmer 5. Farmer 5, despite having a negative enabling leadership is contributing to reaching consensus by being an echoing leadership. This comes from its high number of connections.

If a dissatisfied farmer is more connected to other dissatisfied farmers its enabling leadership is reduced, since other agents take some of this responsibility by influencing such key individual while the echoing leadership will increase excessively. On the other hand, if such farmer is more connected to satisfied agents its enabling leadership will increase while the increase in the echoing leadership increase is not that outstanding anymore.

At the end of experiments analyzed for the hypotheses it is interesting to see the emergent outcomes in case an agent has more than one differentiating characteristic. Farmer 34 was given higher prestige and more number of connections in this experiment. As you can see from the plot in figure A.35, this key individual is the only agent who is showing any leadership indicator and these indicator are quite high.

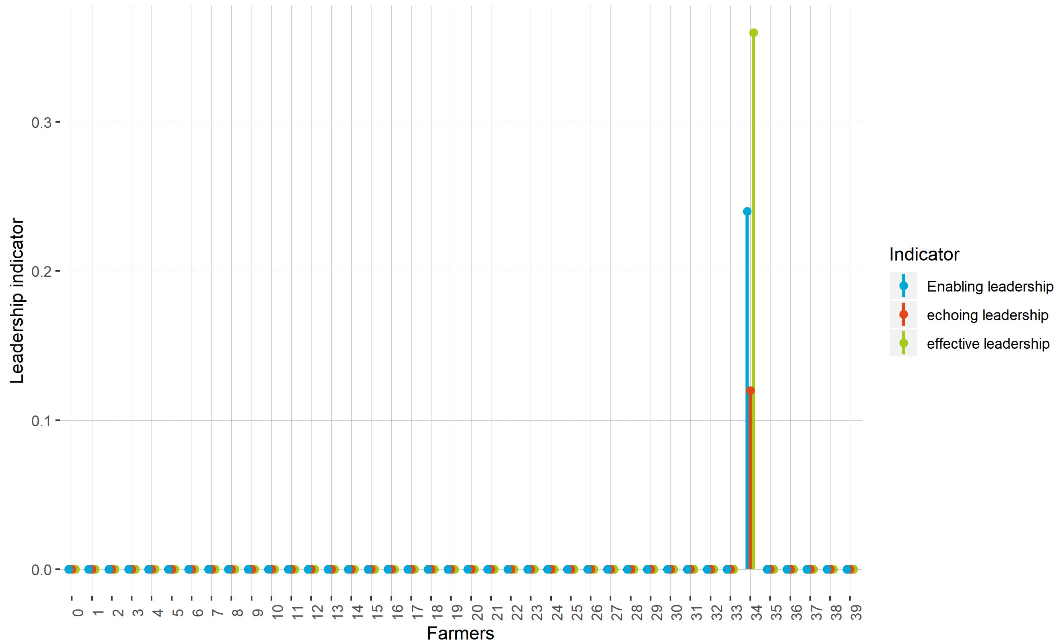


Figure A.35: Leadership indicators of agents in the scenario where farmer 34 is prestigious and has extra connections to mostly satisfied farmers

More experiments similar to this one are performed and it is possible to deduct from them that if an agent has multiple differentiating characteristics, the outcome patterns will be similar to an aggregation of the behaviors (but not the exact numbers) that were discovered through experiments designed for this model's hypotheses.

A.3. The last step

At this stage the model is developed to a satisfactory level, verified and validated with a water expert who is the external supervisor for this study. Until now, the experiments that were performed were aimed at increasing the understanding of the behavior of model components, impacts of different factors and mechanisms through which model behavior emerges.

Now, it is time to reap the benefits of the model to the fullest. With regard to the main research question and the sub-question that relates to this chapter some hypotheses are defined. The model is modified to enable implementation of experiments which provide insight about the validity of these hypotheses. These changes only relate to reporting KPIs and viability of the model in extreme inputs and no mechanism is affected by it.

From previous experiments it is know that the social network has an undeniably important role. Therefore, in this section, attention is given to the design of social networks and their analysis. Factors that greatly impact the social network are the position of agents and the block which they belong to. Thus they are part of social network creation. This is done in R, saved as CSV files and used as inputs for the model, similar to previous steps of the modeling process.

Since population of agents, and farm sizes can be different, the system-level KPI of ecological pressure needs to be changed. The initial total water is re-scaled in setup phase of the model run based on the total farm sizes to keep the ratio of 1.5 between the initial total water and total farm sizes as it was in the previous step of the model. Ecological pressure at time t (EP_t) has a new definition (equation A.14).

$$EP_t = \frac{TW_0 - TW_t}{TW_0} \tag{A.14}$$

Ecological pressure can have values between 0 and 1. This allows meaningful comparison of results between different experiments.

Because of the experiments that are done by inputting different random networks in the model, it is possible that some networks include a isolated sub-group or a sub-group that is connected only through one connection to the rest of the community. In these experiments, it might be possible that in the normal phase or in the phase that is done for calculation of effective leadership, reaching consensus is not possible. Therefore, the model is modified to report ecological pressure of 1. Ecological pressure is equal to one only if there is no water in the system! Therefor, this value can be used to represent situations where consensus was not possible. The consensus time will be reported as zero in these cases.

Idea generation possibility of every agent in the system might also be negative, which is because every agent is satisfied. In these cases no idea generation should happen, therefore another constraint on idea generation possibility is set, so that there is no idea generation if every agent is satisfied.

When ecological pressure changes, the ecological system has changed. Since potential dissatisfaction can become the final dissatisfaction of an agent just by going beyond a limit, agent behaviors are also different in this new ecological system. Therefore, it was decided to set every variable in the model, except for the total water, back to the scenario default. This way, every time that reaching consensus is proved to be impossible, a new clean start at a different ecological system will happen.

These changes have no affect on the behavior of the model experiments explained in this appendix. This is just as a result of verifying the model for extreme inputs. The only drawback is that it is not possible to see hindrance (negative enabling leadership) of agents.

A.4. Sensitivity analysis

Since the model created here is based on an abstract idea which is hard to measure values for, sensitivity analysis, specially regarding the weights (known as η_x in formalization) used in the model, is performed. These weights are in pairs whose sum is equal to one. Therefore, although there are six weights, only three sets of experiments are needed for them. The ratio between these weights are defined as $\alpha_{a,b}$ which is equal to η_a/η_b. So, there are three ratios, namely, $\alpha_{Diss,P}$, $\alpha_{EI,PC}$, and $\alpha_{PS,TS}$. Other constants that are included in the sensitivity analysis are potential dissatisfaction limit ($PDissLim$), required water per unit farm ($RWUF$), minimum livelihood required water ($MLRW$) and water loss per step (WLS).

The model that is used for the sensitivity analysis is the latest version. The social and ecological network are the same as the base model. For all aforementioned factors except for potential dissatisfaction limit and $\alpha_{PS,TS}$ agents are homogeneous. For potential dissatisfaction limit, farm size and prestige are random input using gamma distribution, similar to the stochastic experiments of chapter 5. The shape and rate parameter for farm and prestige are 0.6, 12, 6 and 24 respectively. For $\alpha_{PS,TS}$ two different sets of experiments are performed. In the first one, the experiments are similar to those done for potential dissatisfaction limit and use random input for farm size. The other set of experiment are a scenario in which agent four has stronger tie strength (0.5) in comparison to the other farmers (0.25), while other agent input variables are homogeneous. At the end, these sets of experiments are grouped to homogeneous and heterogeneous agent input variables.

First sensitivity analysis experiments with homogeneous agent input variables are discussed. Five different experiments are done for each factor in this group. In these experiments, the factor under analysis is set to 0.8, 0.9, 1, 1.1 and 1.2 times its value in the base model scenario. Figures A.36 to A.41 show the results. For better understanding, agent-level and system-level KPIs are separated into two different facets.

In most cases, these KPIs, except of final ecological pressure, show a nonlinear relationship with the factor under study. In fact, this oscillating behavior reduces concerns regarding the arbitrary choice of these constants. Final ecological pressures range of change is only significant in figure A.40, where minimum livelihood required water is changed. This could have been expected since the value of 0.25 was chosen purposefully to create an interesting distribution of dissatisfaction between agents in the beginning of the model. Increasing

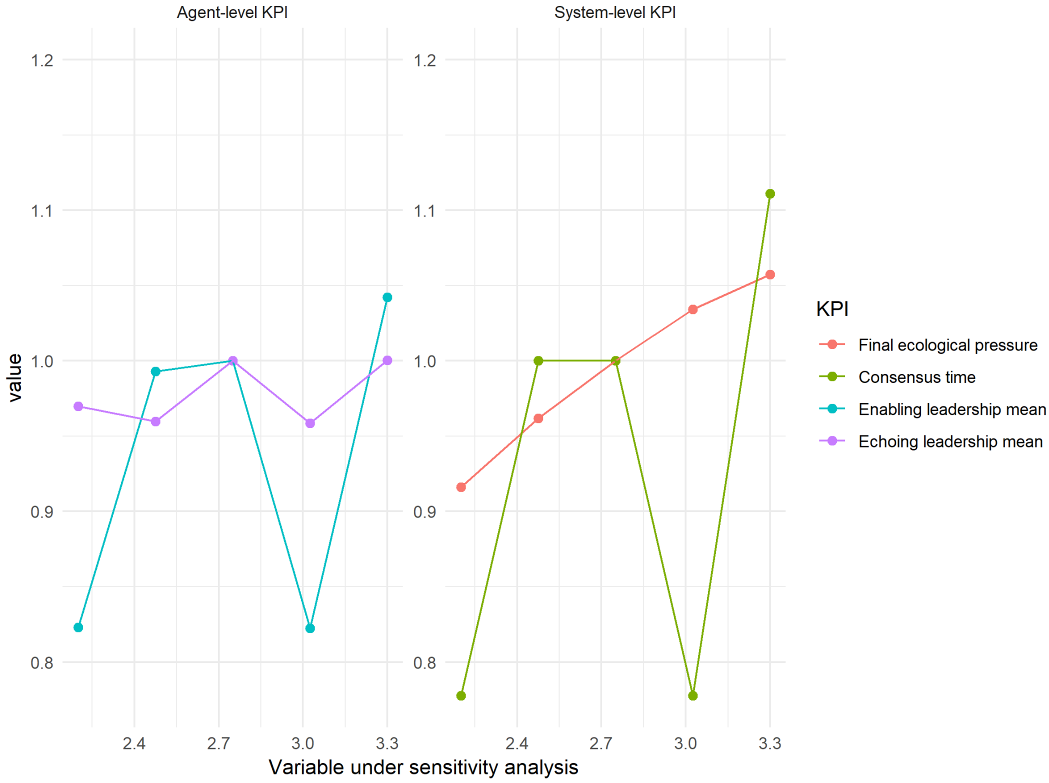


Figure A.36: Comparison of KPIs when $\alpha_{Diss,P}$ is at different ranges with homogeneous agent input variable

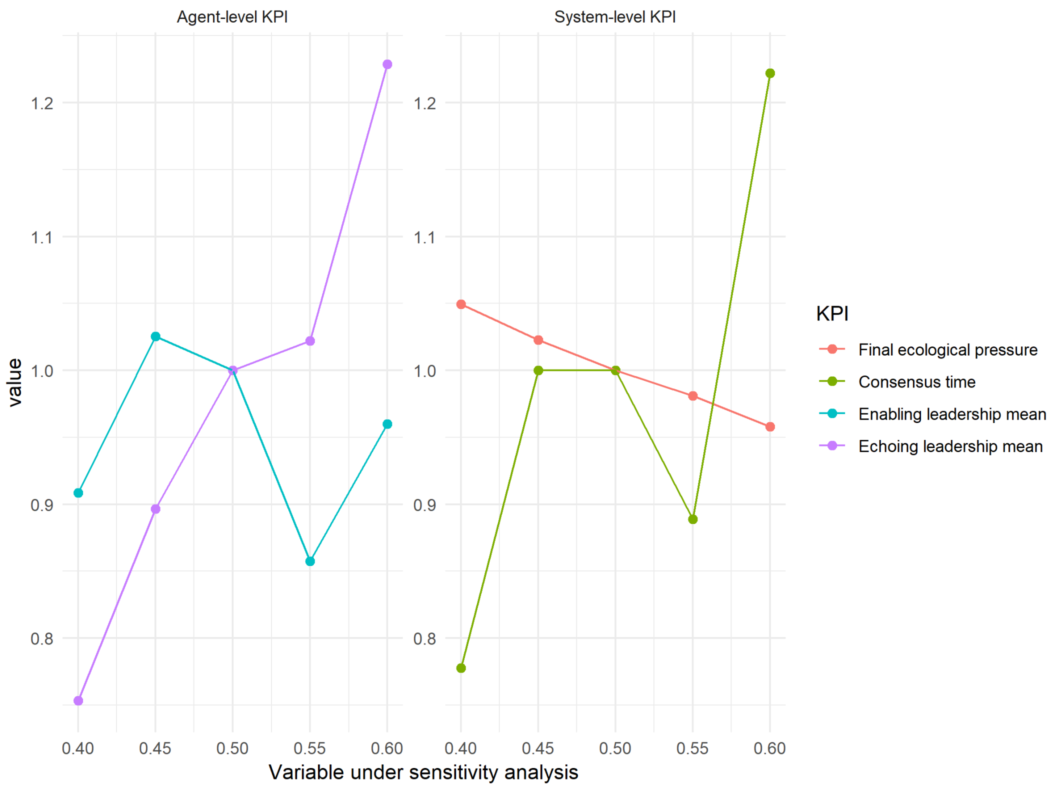


Figure A.37: Comparison of KPIs when $\alpha_{EI,PC}$ is at different ranges with homogeneous agent input variable

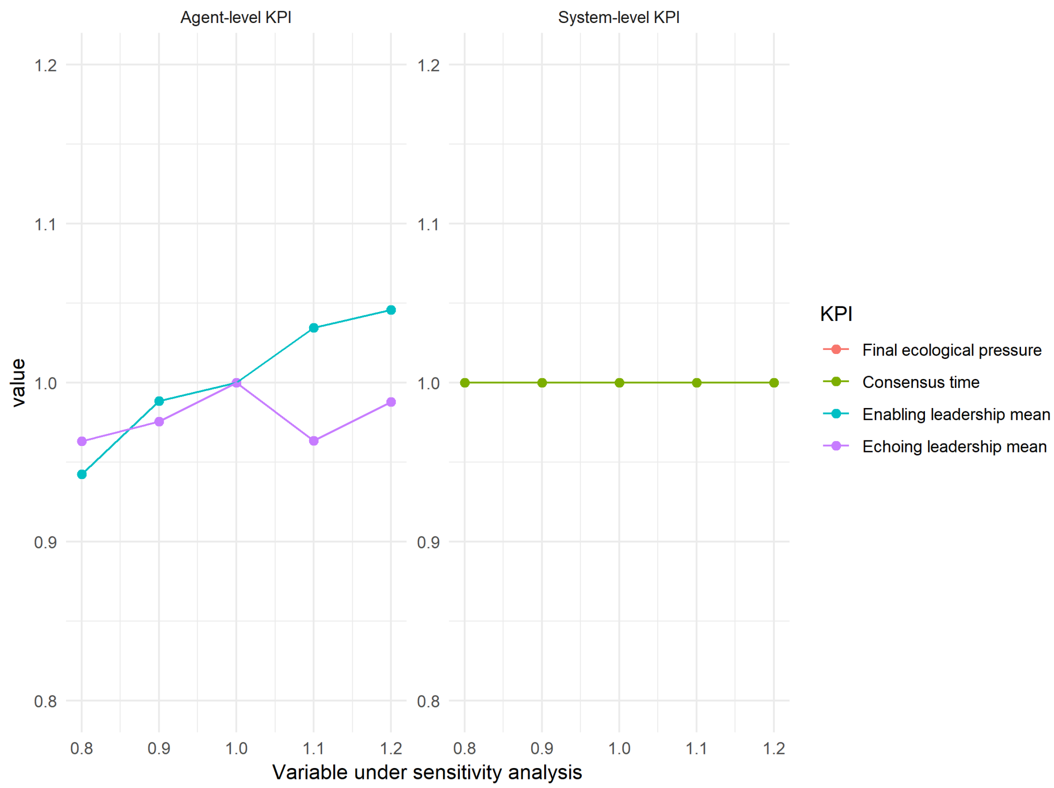


Figure A.38: Comparison of KPIs when $\alpha_{PS,TS}$ is at different ranges with homogeneous agent input variable

this value will easily make more agent dissatisfied and therefore, reaching consensus will be possible at a low ecological pressure. The opposite is also true when minimum livelihood required water is decreased.

Agent-level KPIs show a wide range of change when $\alpha_{EI,PC}$ is changed (figure A.37). However, a closer look at the agent-level KPIs (A.42) show that the agent-level KPIs pattern is almost the same. What matters way more than the final value is the pattern. Main experiments of chapter 5 are based on comparison of the results, not final absolute KPIs. Independence of agent-level KPIs' patterns from different ration of weights ($\alpha_{a,b}$) points out to insignificance of choice of these values.

Changes in the pattern of agent-level KPIs are more noticeable in case of required water per unit farm, minimum livelihood required water, and water loss per step. Again, this is because these variable are chosen to provide a variety of dissatisfied and satisfied agents in the base model. In the end what matters is producing farmers with different dissatisfaction even in the case of homogeneous farm sizes. Therefore, sensitivity of these factors is not an issue at all. Since these factors are closely related to each other and have serious impacts on the outcome the model, if it is needed to change one of them, all of these factors, as well as initial total water needs to considered.

Sensitivity analysis with heterogeneous agent input variables includes two different sets of experiments, one for $\alpha_{PS,TS}$ and the other for potential dissatisfaction limit. It was known from stochastic experiments of chapter 5 that for proper comparison of different scenarios 1600 replications are needed. This high number of replications forced me to limit the sensitivity analysis of each of these two factors to 0.8 and 1.2 times value of the base model. Figures A.43 and A.44 show the results of these experiments.

As you can see from figure A.43, changes in $\alpha_{PS,TS}$ have negligible impact on the final KPIs of the model. Potential dissatisfaction limit, on the other hand, has significant impact on the model. Considering its importance in calculation of dissatisfaction and previous discussions in this section about importance of variables that determine dissatisfaction, it shouldn't be surprising. Results from figure A.44 has an interesting insight as well. Both system-level

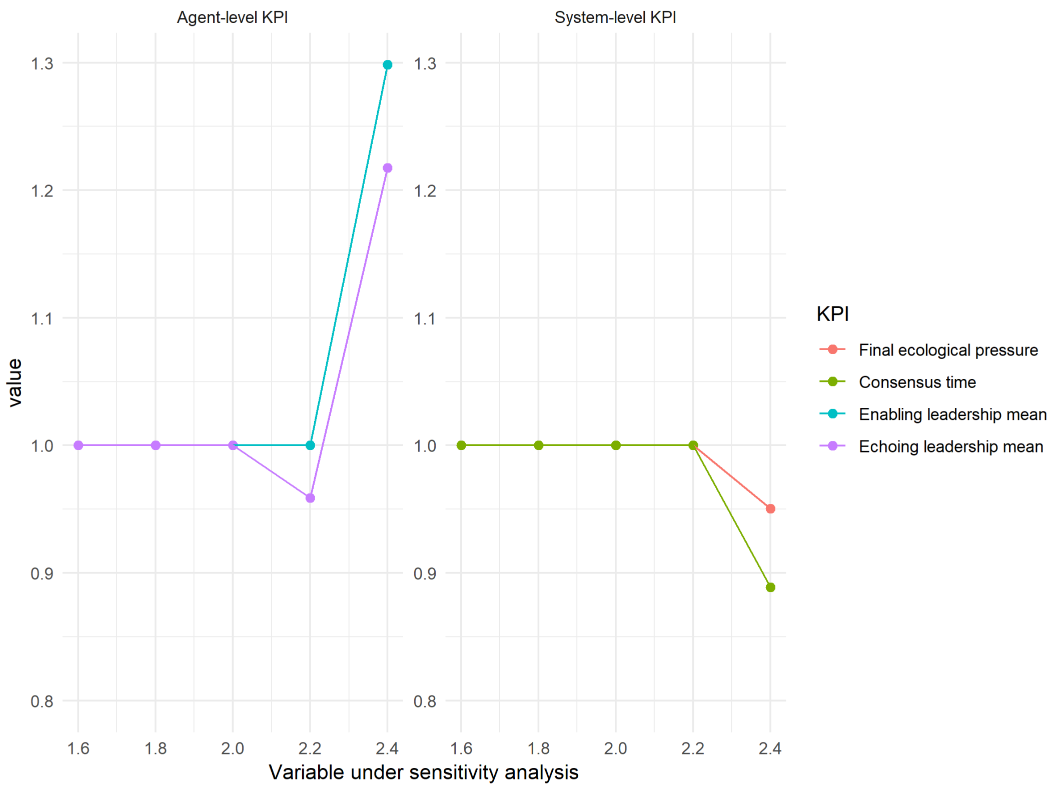


Figure A.39: Comparison of KPIs when required water per unit farm is at different ranges with homogeneous agent input variable

and agent-level KPIs increase when potential dissatisfaction limit increases. This is because some of the agents with big farm sizes that used to become dissatisfied at a specific ecological pressure now need more ecological pressure to become dissatisfied. Now they are reporting their water dissatisfaction that is negative. As a result, other agents have to convince them (higher leadership indicators) and to be able to do so, there is a need for more ecological pressure (so that they have more dedication or farmers with big farm sizes are less satisfied).

All in all, from the results of all sensitivity analysis experiments it is possible to conclude that constants except for those that are used in calculation of dissatisfaction have insignificant impact on model outcome and model behavior can be seen independent of them. The other set of constant, which are used to calculate dissatisfaction, can be further analyzed to understand how they affect results from the main experiment. Between these variables, only potential dissatisfaction limit has high importance, because others are designed in relation to each other to create a dissatisfaction distribution among agents. However, potential dissatisfaction limit, determines how farmers with big endowment behave. I suggest using this variable for further analysis of the model. Limited time and scope of a master thesis did not allow such analysis for this report.

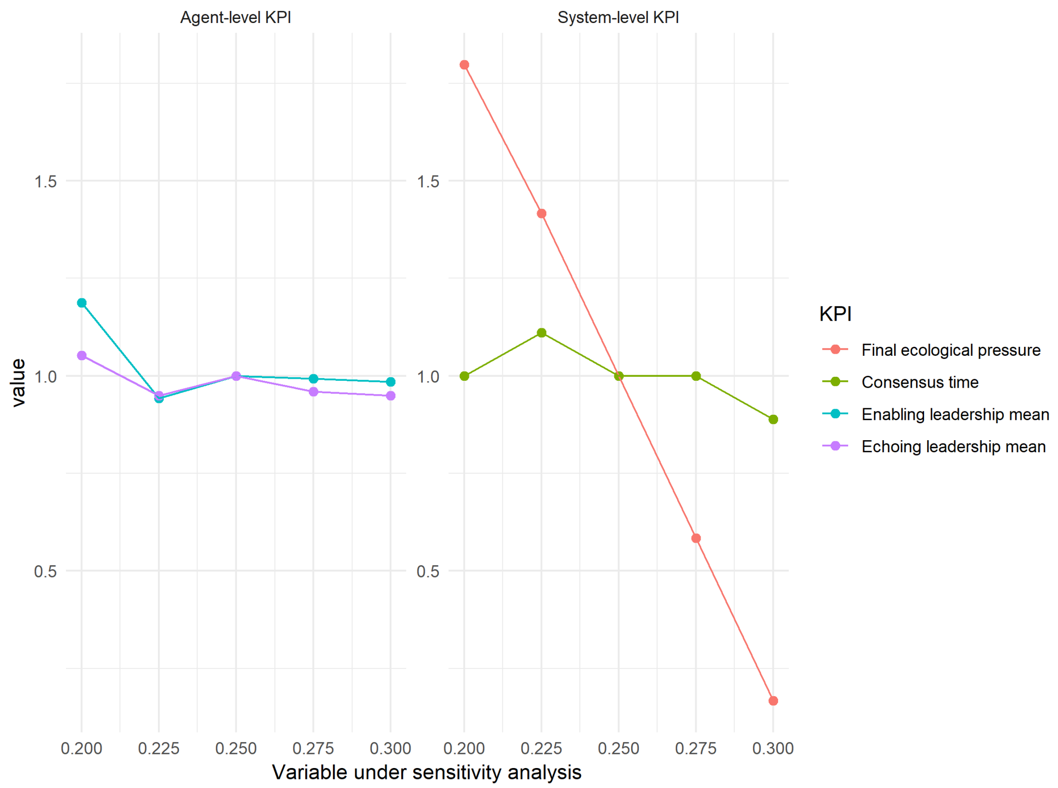


Figure A.40: Comparison of KPIs when minimum livelihood required water is at different ranges with homogeneous agent input variable

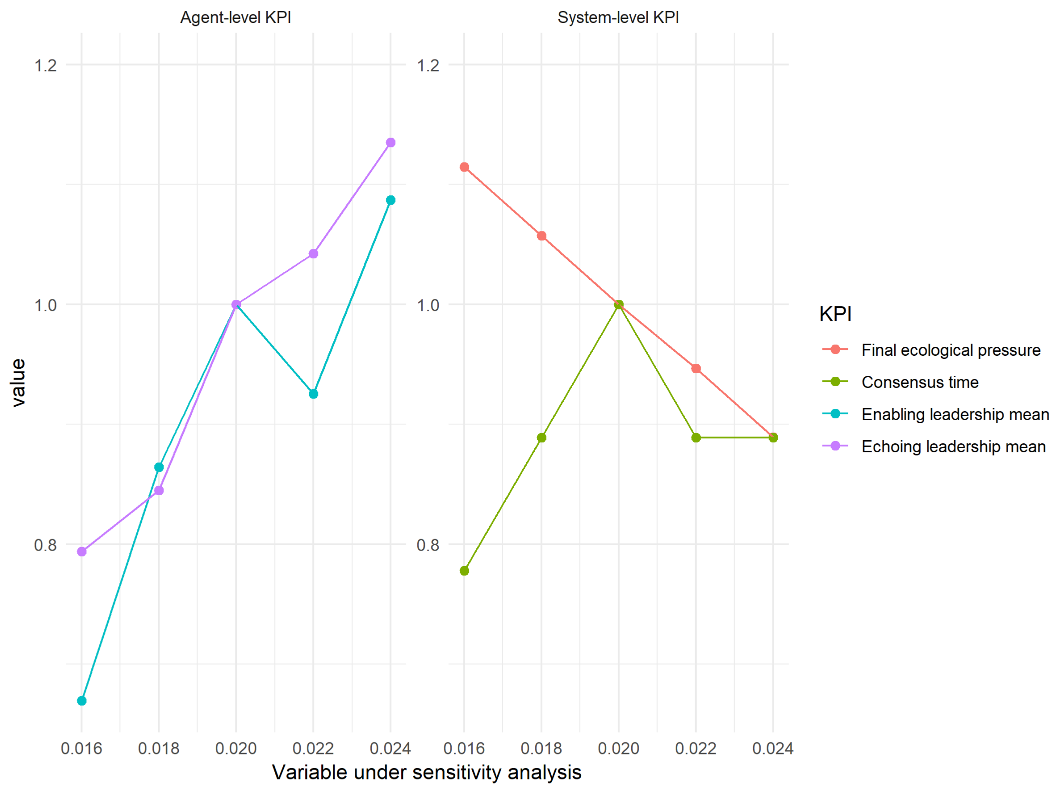


Figure A.41: Comparison of KPIs when water loss per step is at different ranges with homogeneous agent input variable

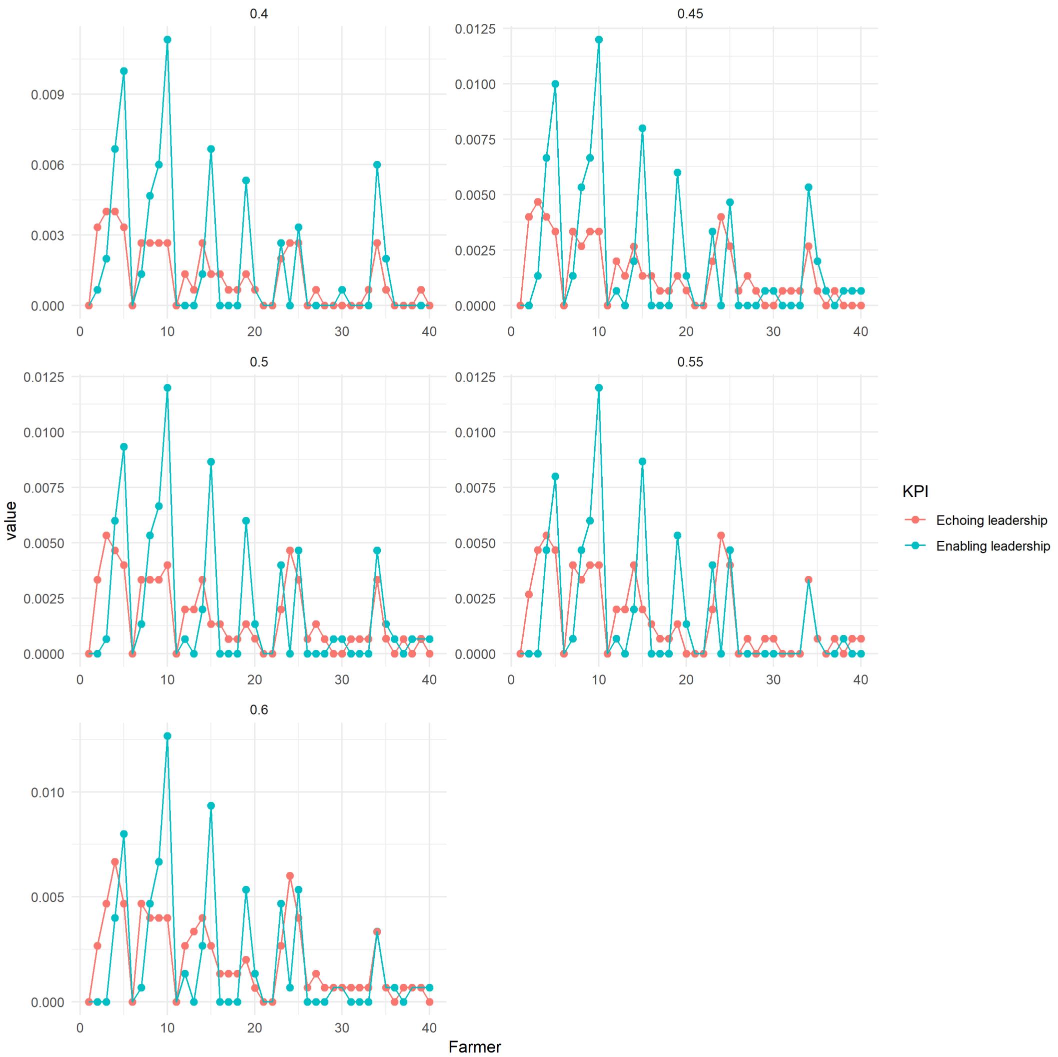


Figure A.42: Comparison of agent-level KPIs when $\alpha_{EI,PC}$ is at different ranges (on top of facets) with homogeneous agent input variable

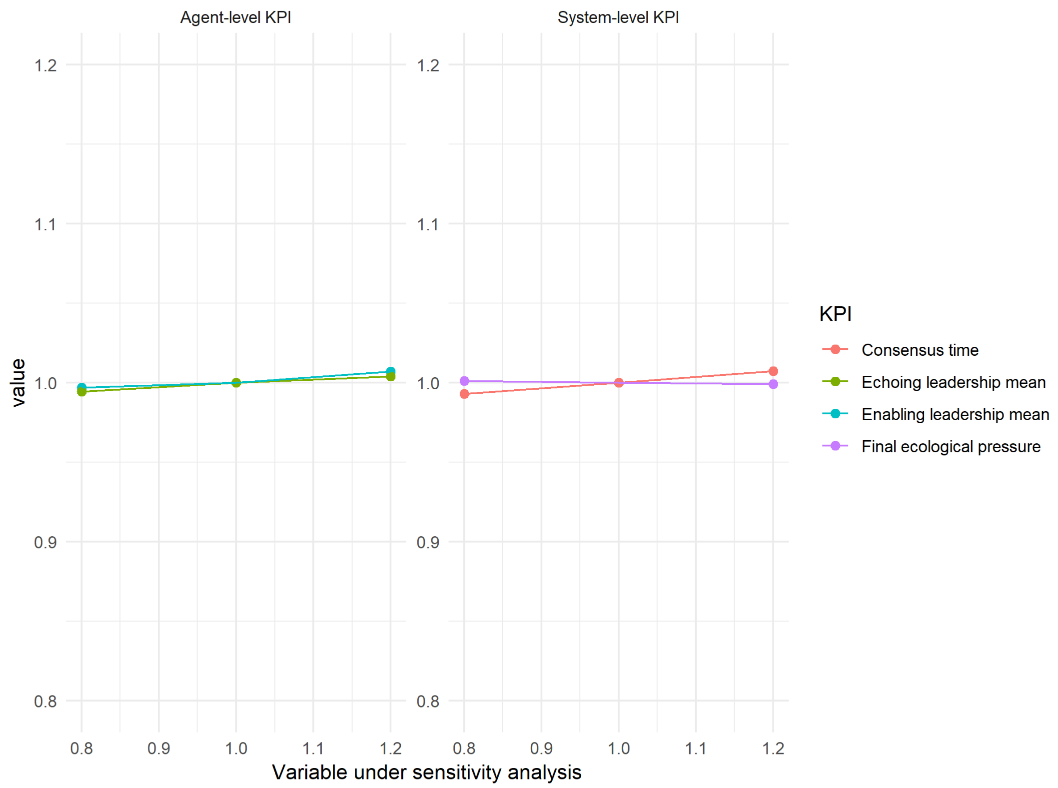


Figure A.43: Comparison of KPIs when $\alpha_{PS,TS}$ is at different ranges with heterogeneous agent input variable

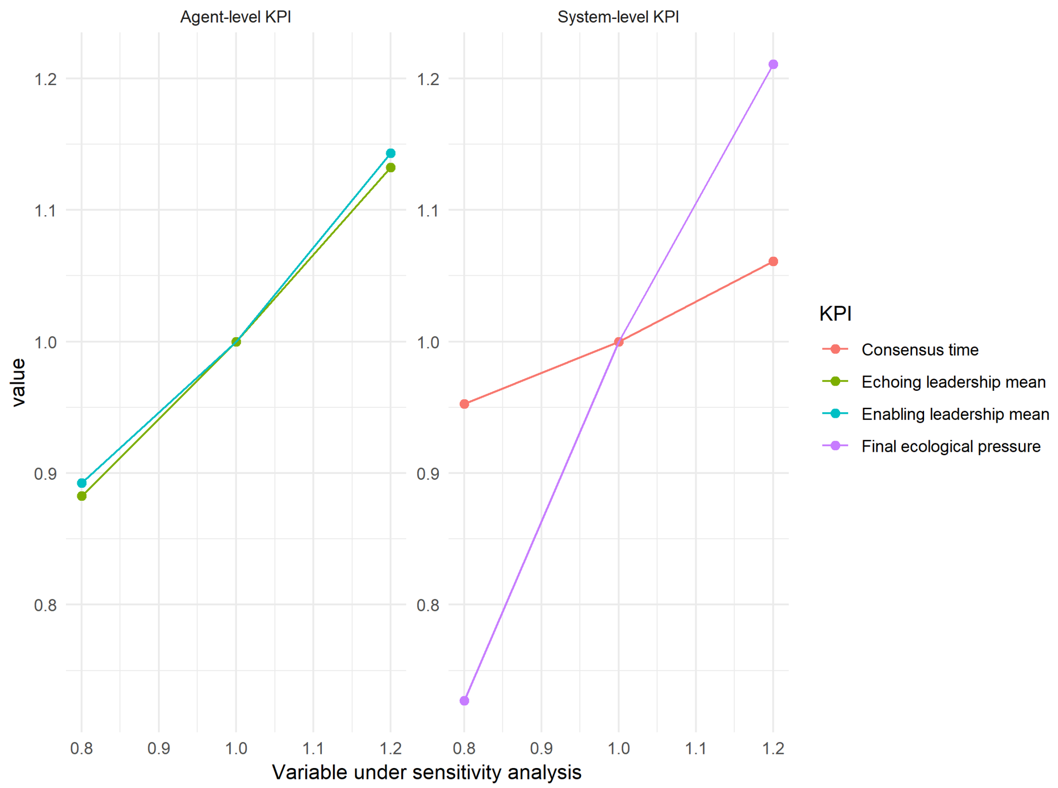


Figure A.44: Comparison of KPIs when potential dissatisfaction limit is at different ranges with heterogeneous agent input variable

B
Wilcoxon signed-rank test results for network experiments

In this appendix Wilcoxon test result based on their p-value are plotted into heatmaps. In each figure, the legend indicates the p-value that corresponds to each color. To read scenarios the user needs to find the right combination of population (gold), density(blue), degree centralization (red) and betweenness centralization (black). These plots are used to conclude significant changes in the final results of network experiments in chapter 5.

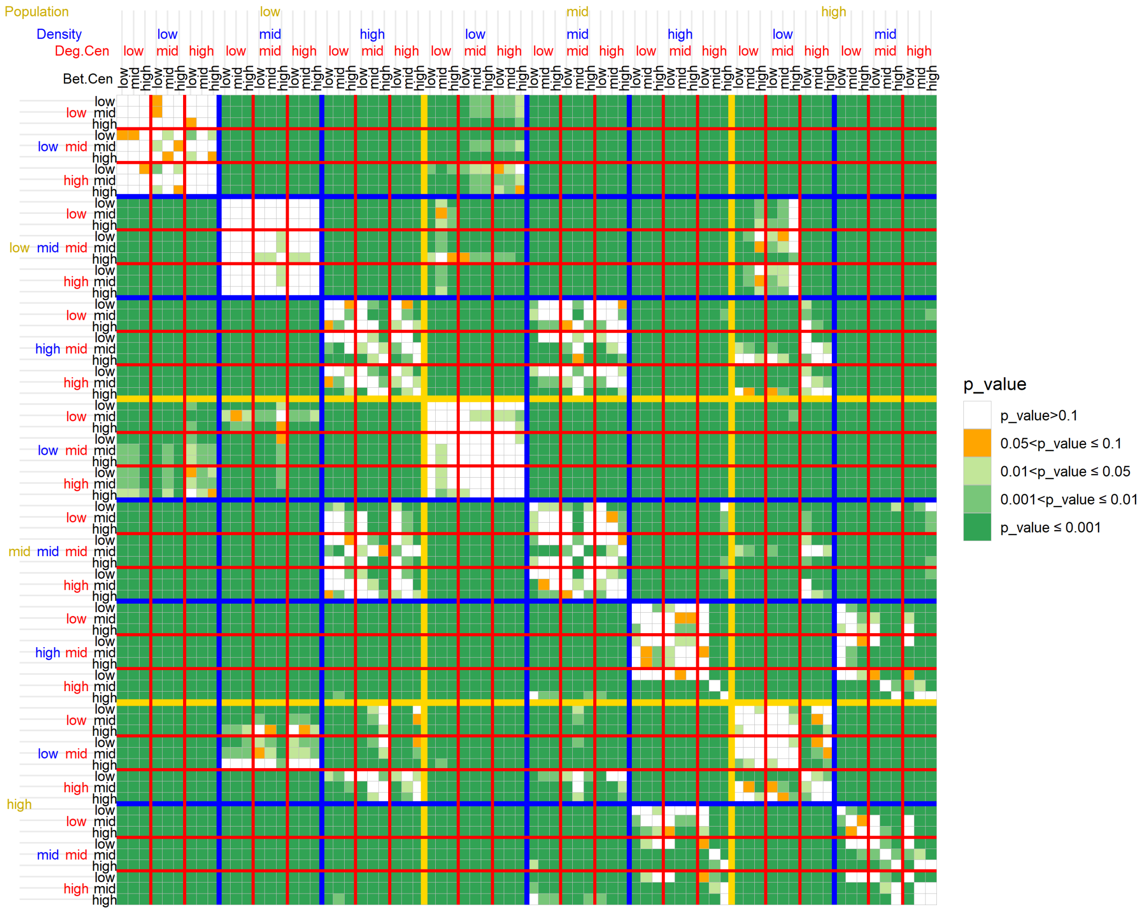


Figure B.1: Wilcoxon signed-rank test result for final ecological pressure. Green squares represent p-value of below 0.05 between two different scenarios.

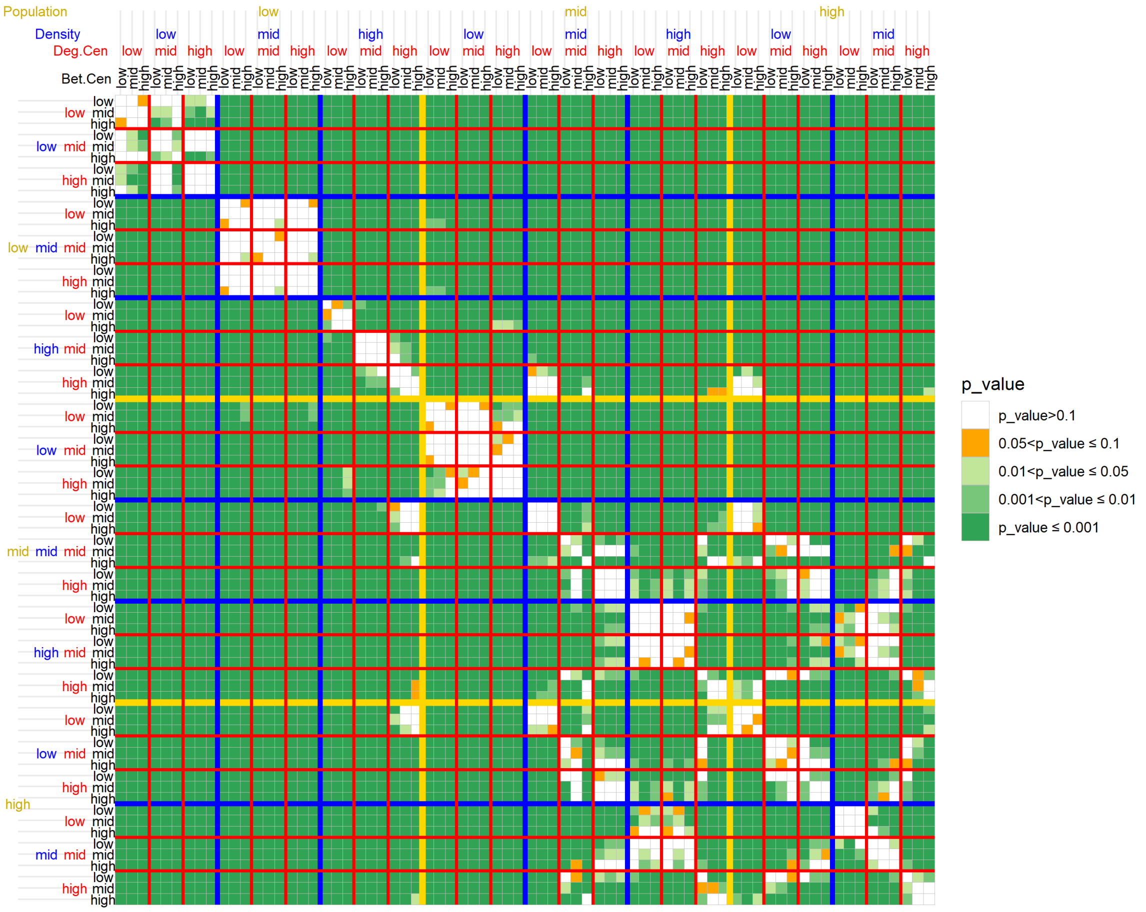


Figure B.2: Wilcoxon signed-rank test result for consensus time. Green squares represent p-value of below 0.05 between two different scenarios.

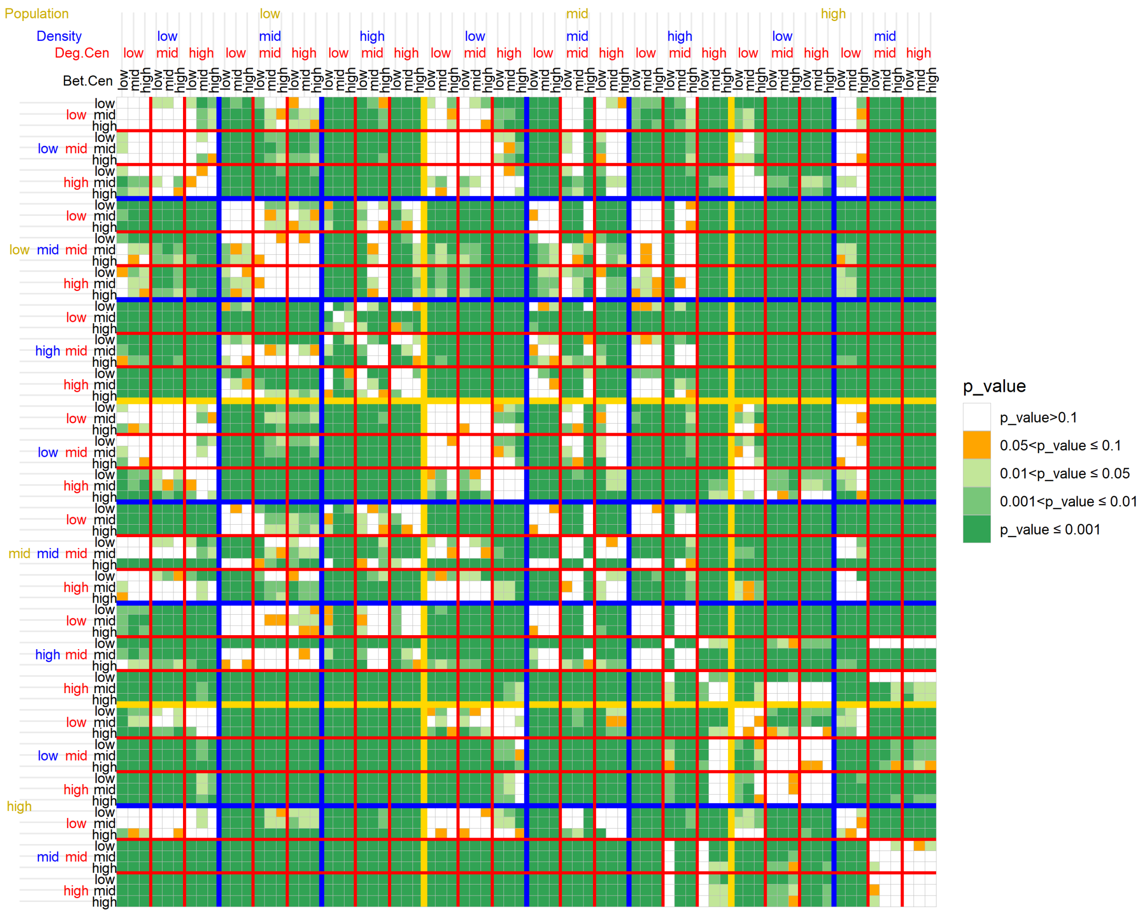


Figure B.3: Wilcoxon signed-rank test result for enabling leadership mean. Green squares represent p-value of below 0.05 between two different scenarios.

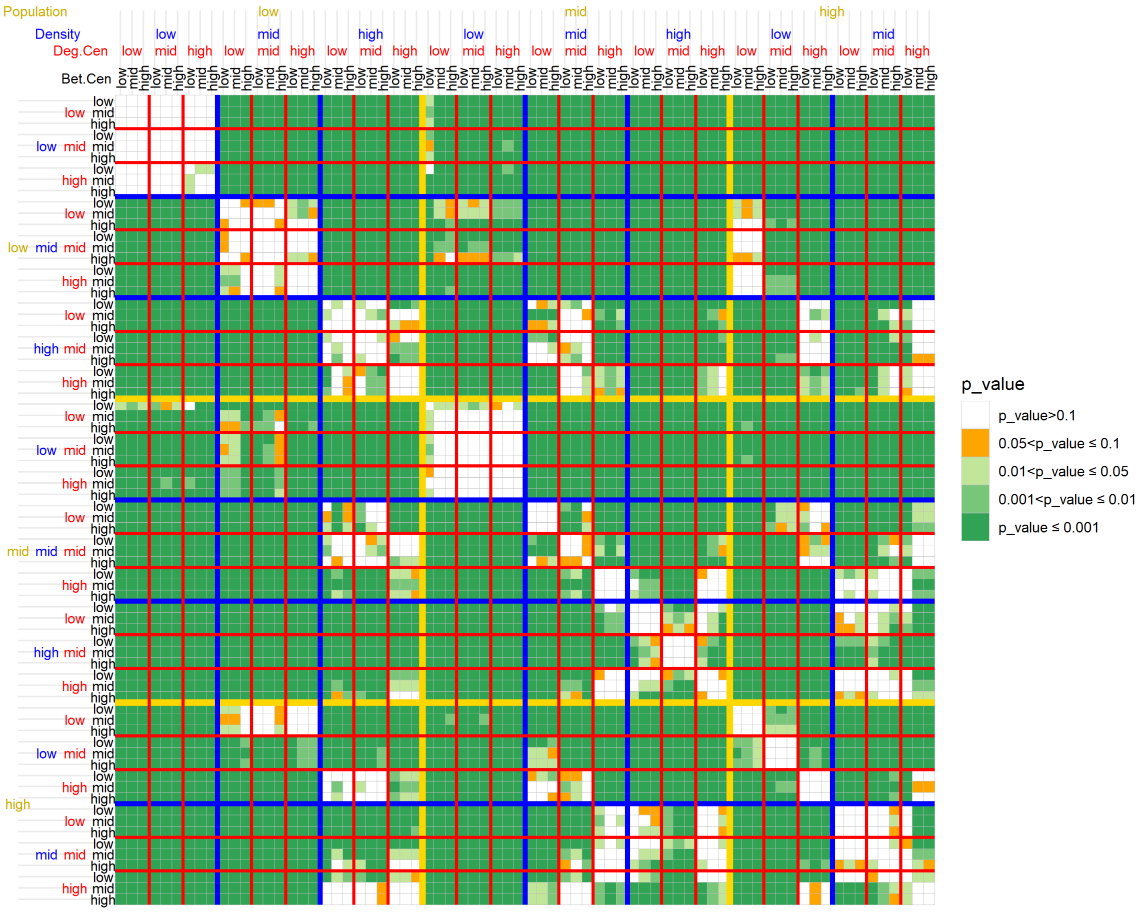


Figure B.4: Wilcoxon signed-rank test result for echoing leadership mean. Green squares represent p-value of below 0.05 between two different scenarios.

C

Wilcoxon signed-rank test results for stochastic experiments

This appendix has a similar purpose as appendix B. In this appendix Wilcoxon test result based on their p-value are plotted into heatmaps. In each figure, the legend indicates the p-value that corresponds to each color. These plots are used to conclude significant changes in the final results of stochastic experiments in chapter 5.

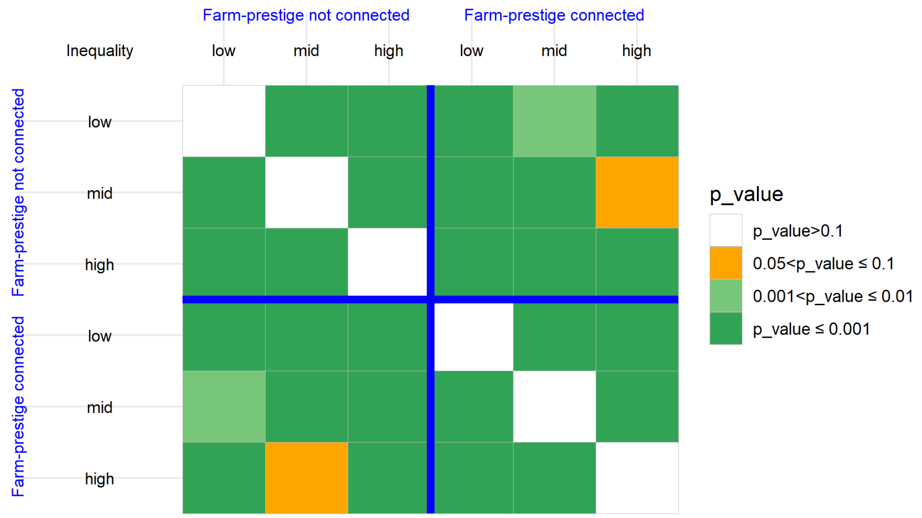


Figure C.1: Wilcoxon signed-rank test result for final ecological pressure. Green squares represent p-value of below 0.05 between two different scenarios.

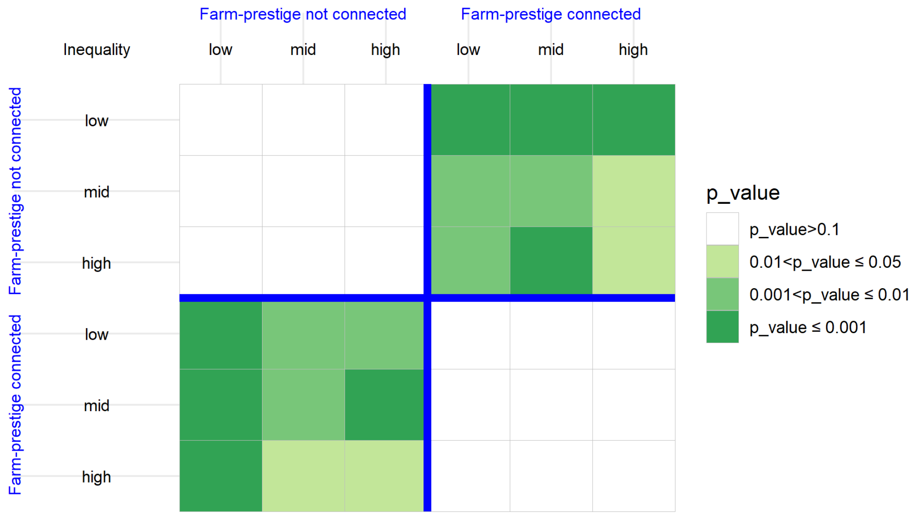


Figure C.2: Wilcoxon signed-rank test result for consensus time. Green squares represent p-value of below 0.05 between two different scenarios.

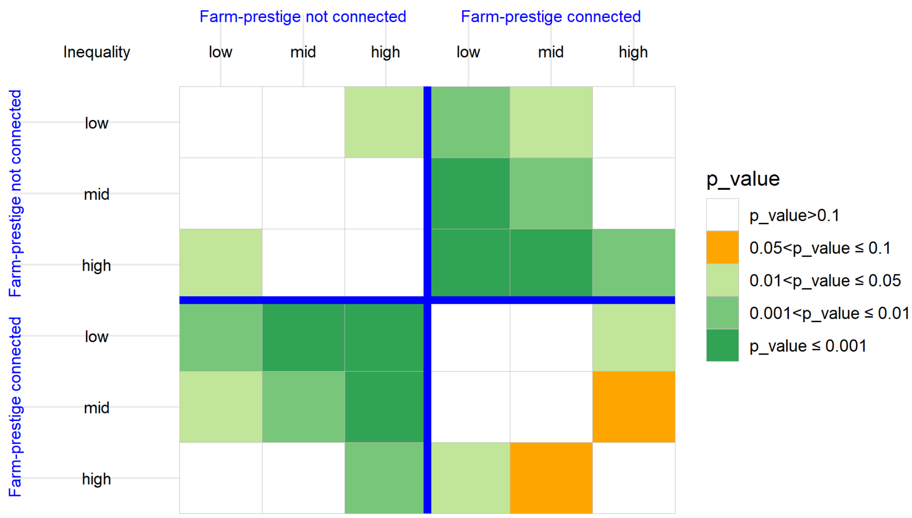


Figure C.3: Wilcoxon signed-rank test result for enabling leadership mean. Green squares represent p-value of below 0.05 between two different scenarios.

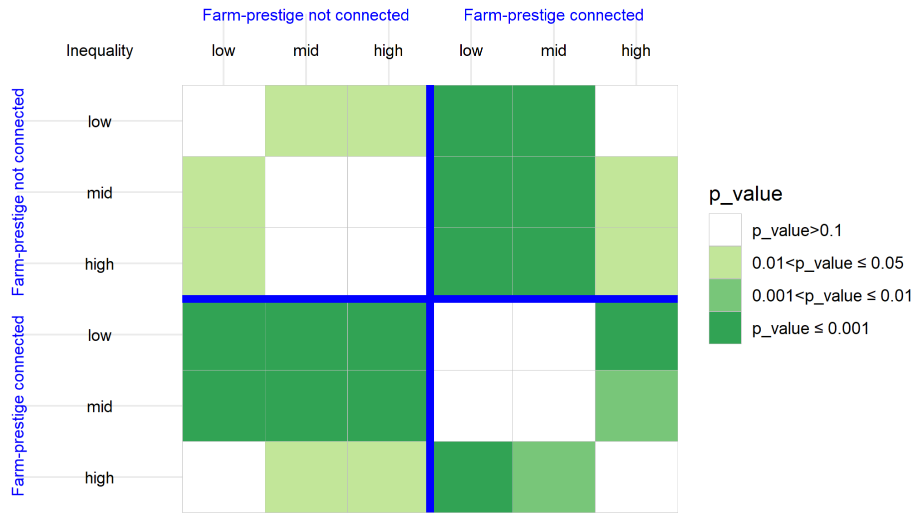


Figure C.4: Wilcoxon signed-rank test result for echoing leadership mean. Green squares represent p-value of below 0.05 between two different scenarios.

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