Encoding social learning on public policies for rural water in Uganda

Exploring the Applicability of Memetics

Felix Sylvester Knipschild
f.s.knipschild@student.tudelft.nl

Abstract

Social Learning receives increased attention as a fundamental approach to cope with complexity and uncertainty in a system. Much research is done to add understanding to social learning. However, little research focusses on computer-based simulations to enhance understanding of social learning processes. This paper adds understanding to social learning processes in rural water supply system by encoding social learning in an Agent-Based Model. Social learning processes are encoded using the theory of memetics. In a case study the effect of different social learning processes on the performance of the rural water sector in Uganda is explored.

The use of Agent Based Modelling and computer-based simulations enlarged understanding about social learning processes in a multi-level governance system. The theory of memetics enlarged the understanding of encoding social learning processes as it forces a modeller to make conscious choices in conceptualising the necessary conditions for a loop of evolution - selection, replication and variation. Future research should focus on replication of this study with a heterogeneous relation between policy and implication of the policy, with lower institutional levels and with case study in other types of systems than rural water supply.

Keywords: Agent Based Modelling, Uganda, Water Sanitation and Hygiene, Multi-level Governance, Memetics

Delft University of Technology
Faculty of Technology, Policy & Management
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1 Introduction

Social learning describes the process in which people learn from each other by making observations and by abstracting information from those observations. People can use the abstracted information to make conscious decisions in future situations. Social Learning is getting increased attention in natural resource management as a fundamental process to deal with uncertainty and complexity [Cundill et al., 2012, Pahl-Wostl, 2009]. Social learning can allow individuals, groups or networks to develop knowledge, values and competence that enable effective problem solving.

Much research into social learning is focussed on water resource management. The premise of social learning is that actors in a system learn how to allocate resources more effectively. Maarleveld and Dabgbégnon [1999], for instance, use social learning as a means to facilitate collective decision making and Pahl-Wostl et al. [2007a] describe the role of learning in managing change in water resource management. Policy makers use social learning as a means to deal with complex situation, by implementing structures in a system that enable social learning processes between actors [Jiggins et al., 2007, Ison and Watson, 2007, Steyaert and Jiggins, 2007]. Consequently, there is a relation between social learning processes in a system and the governance structure of a system. Pahl-Wostl et al. [2007b] emphasise the interaction between social learning and the governance structure of a system by stating that social learning processes are influenced by the governance structure of a system and that social learning processes can change a governance structure. Social learning processes can also contribute to water resource management practices in rural areas. An example is provided by Gleitsmann et al. [2007] who investigate how social learning processes can be stimulated by a platform for social actors in rural Mali. Another rural application of social learning processes is provided by Moriarty et al. [2005] who study the effect of stakeholder platforms on horizontal and vertical information spread in a multi-level governance environment, thereby arguing for a relation between governance and social learning.

Less research on social learning in water management explores the possibilities of computer-based simulations to analyse learning processes. Social learning in a water supply system develops and changes over a period of multiple years. There are many variables that influence structures that foster social learning and there are many actors consciously or unconsciously involved in social learning practices. Aforementioned research shows how promising effective social learning processes are. A policy maker involved in water resource management could benefit from a method to test implications of a policy on the effectiveness of social learning processes. Computer-based simulations provide a promising way to perform these test in a relatively short period of time. One of the greatest challenges is to find a computer-based method that can simulate human behaviour, as social learning processes are a result of the behaviour and interactions between humans. Agent-Based Modelling is a computer-based simulation method that is able to simulate human behaviour. This is acknowledged by Pahl-Wostl [2002], who introduces Agent Based Modelling (ABM) as a novel approach to analyse the effect of human behaviour in natural resource management. According to this research a modeller can use *agents* to represent human behaviour by encoding their decision rules. Pavón et al. [2008] research the use of ABM to model patterns in social dynamics. ABM allows this type of modelling, because an agent can have a mental state and interact with other agents in an environment, which enables to observe the effect of interactions between agents. In Bousquet and Le Page [2004] an application of Multi-Agent Systems modelling is presented to understand behaviour and interactions between multiple agents in ecosystem management. There are little examples where ABM is used to analyse social learning processes in a rural water supply system. Hare and Deadman [2004] provides an example by constructing a taxonomy of Agent-Based Modelling and Simulation for environmental modelling, where they describe amongst others four cases where ABM is applied to a rural water supply sector.

This paper focusses on the possibilities to encode social learning in a financial resource case into an Agent-Based Model in order to simulate, gain results and compare with reality. The aim of this paper is to increase understanding of social learning processes in a rural water supply system in general. This is done by showing how ABM can be used to encode social learning processes. In this paper social learning processes social learning processes are encoded from the perspective of cultural evolution. The theory used for the implementation of social learning in an ABM is memetics. This paper shows that this helps us to learn about social learning processes in general and how it generates sensible policy implications in the system of interest.

In this paper theory on the applicability of social learning and Agent-Based Modelling is provided in section 2. This is followed by section 3 about methodology where the we explain how theory of cultural evolution is used to describe learning processes and an introduction to the case study is given. In section 4 we show an example of the implementation of memetics to represent social learning processes in the case study. The paper is concluded with a discussion of the contributions of this paper to encode social learning in an Agent-Based Model. The advances made are highlighted and encouragements for further research are presented. The discussion shows how the theory of memetics can lead to enhanced understanding of social learning processes in a rural water supply system.

2 Social Learning in Agent-Based Models

This section described how elements of social learning can be represented in an ABM. Social learning describes the process in which people learn from each other by making observations and by abstracting information from those observations. Based on the information that is abstracted from the observations people or actors in a system make decisions. No matter how complex the system or the decision to be made, decisions are finally taken by individuals or as a result of interactions between a group of individuals [Pahl-Wostl, 2002, p. 405]. A precondition for social learning processes is the presence of a shared problem understanding between the actors that are involved in the decision-making task [Pahl-Wostl, 2002, p.400]. When this and conditions such as trust and a joint reflection on the systems dynamics are present social learning can provide the means to facilitate different forms of collective decision making [Maarleveld and Dabgbégnon, 1999]. The modelling environment of an ABM should enable the translation of these types of processes and dynamics into a computer-based simulation in order to effectively model social learning processes. In an ABM actors can be represented by *agents*, which are autonomous software systems that can be given a state and can interact with each other in an environment [Dam et al., 2013]. Agents can describe the behaviour of observed social entities by encoding their decision-rules and therefore ABM can be a very promising method to capture the human dimension in the analysis of a system [Pahl-Wostl, 2002, p. 404]. Furthermore agents can be given a certain goal. Actors in a system aim for a specific target in their decision-making processes and therefore agent must represent a similar goal-seeking behaviour. Stephen Lansing and Kremer [1993] provide an example study where they provide agents in an ABM a certain goal and let them interact in a social network. The agents consider their state, decide if their goal is reached by that state and perform an action to either move towards that state or to retain the state. Another implementation of goal-seeking behaviour of agents is provided in Janssen [2001].

Revisiting the research by Stephen Lansing and Kremer [1993] we see another important element of social learning represented. The research assesses whether simulation models are appropriate to address processes of adaptation in complex social systems. In processes of adaptation we can see how actors in a social network act and interact based on the actions of each other. This represent processes of social learning, as social learning occurs through actions and interaction between actors in a system who try to learn from each other. In the research the ABM is used to represent the social dynamics of a system of water temples in rural areas in Bali [Stephen Lansing and Kremer, 1993]. So called *subaks* (the agents) represent an irrigation system and the decision-making entity of the subak. The subaks mutually influence each other: actions of one subak influence ecosystem variables of another subak, thereby altering the *fitness landscape* of other subaks and also the future decisions of the other subaks, as these are assumed to be made based on their fitness to the environment. The fitness of an agent to its environment determines how well the state of the agent corresponds to its goals. A link is made to the theory of complex adaptive systems: agents (subaks) interact in a network, causing aggregated emergent behaviour [Stephen Lansing and Kremer, 1993, p. 110]. The agents consider their state and they base their actions on their state so as to maximise some sort of value. This type of behaviour of a system is represented in an ABM, as we can observe the cumulative effect of individual decision-making of agents. The ABM should include interactions between technical and social elements in a system [Janssen, 2001]. A social network of actors strongly interacting with a technical system makes the system a Complex Adaptive System (CAS). In a CAS the social network of actors defines the development, operation and management of the technical system, which in turn influences the behaviour of the actors within the social network [Dam et al., 2013].

Another perspective on social learning is provided by theory on cultural evolution. In this perspective social learning represents how information, ideas or policies spread through a social system. Haggith et al. [2003] investigate the diffusion of ideas across social networks using the theory of memetics. The research aims to analyse the relation between social networks and the way ideas are spread around communities. It provides insights in what characteristics of social networks enable or hamper effective spread of ideas. To understand social learning from the perspective of cultural evolution we have to consider the information as subject. In memetics the piece of information is considered a *meme* [Marsden, 1998]. Memes can differ in their degree of fitness to their environment, i.e. they are or are not sufficiently adapted to the socio-cultural environment in which they propagate. Fitter memes are likely to be successfully communicated more often than less fitter memes, resulting in a larger spread over a population. An example of memetics as a form of social learning is provided by a songbird experiment [Lynch, 1996]. In this research *song* is transferred from generation to generation via processes of social learning. Two basic requirements in the evolution of the *songs*, variability and heritability, allow us to observe development of songs in bird species as processes of cultural evolution.

3 Methodology

This section describes how social learning is implemented on a financial resource case in an ABM. The concept that is used to guide the process of encoding social learning is derived from the theory of memetics. Haggith et al. [2003] describe the potential for analysing the spread of ideas in a social network with the theory of cultural evolution. In this paper we follow the theory of *memetics* to encode social learning processes. In subsection 3.1 the translation of social learning processes to memetics is made. Next, in subsection 3.2, a case study is introduces. In order to analyse the effectiveness to describe and analyse social learning processes with the theory of cultural evolution using an ABM a case study of a rural water supply system is selected. The case study is about rural water in Uganda, as much information and expertise about the policy framework and the multi-level governance situation is available to the modeller.

3.1 Application of Memetics Theory

Memetics theory states that human condition is influenced by at least two selective processes: biological (genetics) and social (memetics) [Marsden, 1998]. The necessary conditions for a loop of evolution - replication, variation and selection - are present in both processes. These processes act on - i.e. they replicate, variate and select - a similar subject: the gene in genetics, the meme in memetics. A gene can be understood as a unit of biological information and a meme can be understood as a unit of cultural information [Heylighen and Chielens, 2009]. Cultural traits are transferred from person to person and in that process the cultural trait, the meme, is subject to processes of replication, variation and selection. A meme can be defined as an information pattern that is held inside the memory of a person, and which can be copied to the memory of another individual [Heylighen and Chielens, 2009].

In this paper the *meme* is used to represent a policy. We analyse how policies are spread through a system. We are interested in when actors take up a policy from another actor and what happens when actors all start communicating the effectiveness of their policies. This is how social learning processes are represented in this research: we look at the communication of policies between actors within a system. Following the theory of memetics the actors are not the subject of the analysis, but the policies are. We look at how the policies are communicated and when they are taken up by other actors.

For the implementation of memetics in an ABM the processes that are present in a loop of evolution are used: selection, replication and variation. In the selection process the policies follow a procedure similar to natural selection in the genetics. We separate successful policies from unsuccessful ones and propagate the successful ones. The successfulness of a policy is determined by its fitness to the environment. Fitter policies for instance result in better performance of an actor that uses the policy and is therefore more likely to be propagated to other actors. The replication processes is used to determine what policies are replicated by what actors. As we see further on in this paper, this process can describe different scales of communication between actors in a system. The third step, variation, is known in theory on evolution as the process that enables all evolution [Dawkins, 2006]. The variation step in memetics is implemented to add variation to the policies of interest. The addition of variation enables to see how a policy can change and evolve into more and less fit versions. In an implementation in an ABM we can see how and if such a new policy is propagated and taken up by actors in the system.

This is the methodology that describes how memetics is implemented in an ABM to represent social learning processes. The next section describes the case study on which the theory of memetics is applied to.

3.2 Introduction to Financial Case Study

In Uganda a stagnating improvement in water services delivered to rural population is observed. The current coverage in Uganda is 66% [Ministry of Water and Environment, 2015] for a rural population of approximately 37 million people [Trading Economics, 2015]. Decentralisation efforts in Uganda have led to dispersed decision making across sectors, including the rural water supply sector [Government of Uganda, 1997, Ministry of Water and Environment, 2013b, 2012]. The dispersion of decision-making in the sector is from village level to national level and can be described by the concept of multi-level governance. This means that the efforts to provide water services, the processes from policy making to implementation of water service, to the rural population are observed at multiple institutional levels [Da Silva Wells et al., 2013, Magara, 2014]. Uganda is divided in multiple regions that each consist of multiple districts. The total number of rural districts is 110. The districts are made up out of counties and those are divided into sub-counties. The sub-counties consist of villages, parishes and communities. The specific institutional organisation is described in Knipschild [2016].

In order to understand processes of social learning in rural Uganda we look at financial resource allocation in the sector [Ministry of Water and Environment, 2013a, Ministry of Finance Planning and Economic Development, 2016]. In this case study, three institutional levels are abstracted: national, regional and district level. The case enables the identification of social learning processes in the rural water supply system. National level provides districts with a conditional budget to invest in rural water services. In other words, the districts can choose on what infrastructure to spend the budget, as long as they adhere to conditions provided by national level. The national level for instance dictates the budget available to invest in new infrastructure and the budget available for major repairs of water infrastructure.

Districts operate in a social network, acting and interacting with each other [Nabunnya et al., 2016]. The districts can learn each other successful ways to spend the budget from national government within the boundaries set in the grant. Note that the district is analysed as the actor that uses the meme. In rural Uganda three ways are observed that describe how information about a policy is communicated from one district to the other [Nabunnya et al., 2016].

Inter-district learning process: a representative from a district communicates with a representative from another district. The two share their own best practices with each other and learn best practices from the other.

Regional learning process: districts can share best practices and learn from each other in a variety of venues at regional level. Representatives from all districts in a region gather to share information.

National learning process: districts can share information with each other through the Government of Uganda at national level. The actor at regional level can observe and identify successful policies in the districts and communicate this information to the national level. The national level can, in turn, communicate this information back to the districts by means of laws and policies that are set at national level.

There are multiple ways in which districts in the case study communicate with each other about a financial policy. The financial policy is considered as the meme in this research. In the next section a detailed description of the policy is provided. The process of encoding social learning with the theory of cultural evolution in an ABM is applied to the financial case study in the districts in rural Uganda. The case study aims to analyse the applicability of memetics in an ABM to encode social learning processes.

4 Encoding Social Learning in Rural Water Supply in Uganda

This section describes the case study where social learning processes are encoded in rural water supply in Uganda using the theory of memetics. The aim of the case study is to show the applicability of memetics to analyse social learning in a system and to observe the kind of insights that can be generated with such a study. This section starts with a description of the conceptual model of social learning in rural Uganda. Therefore the governance system in Uganda is analysed and in subsection 4.1 we can see how different elements of the system are represented in the ABM. In subsection 4.2 subsequently the application of the theory of memetics on the financial case study is described. The subsection describes how the processes of selection, replication and variation are implemented.

Thereafter the experimental design is described in subsection 4.3. The experiment is used to test different scenarios for the replication and the variation step. In the replication process different scales of communication between the actors in rural Uganda can be represented. In the variation step consequently we aim to analyse the effect of adding variation to the policy of interest. The two processes are described in detail in subsection 4.2, and the experiment is used thereafter to observe different representation of social learning processes. The result of the experiment are described in subsection 4.4. We show how the different scenarios for learning can be interpreted and what kind of insights can be generated with memetics in the system of interest.

4.1 Encoding the Governance System

Throughout the process of encoding critical assumptions are recorded. The conceptualisation is described along the lines of these assumptions. An overview of the assumptions is provided in Table 1 and Table 2 for the two different phases.

Three institutional levels are represented in the ABM to experiment with different structures of how districts learn from each other. National level provides district level with financial support to invest in rural water infrastructure. The districts receive the budget on an annual basis and only receive what they actually spent. National level is assumed to have an infinite budget (Assumption 1 and 2). There are 110 district in Uganda and they are all represented by an agent in the ABM. Real districts are represented in the ABM in terms of name and initial conditions for population, functionality of water infrastructure and water service level. Besides the initial conditions the districts are homogeneous, e.g. in terms of geographical representation and representation of water infrastructure (Assumption 3, 4 and 5). All districts are in a region. In total there are 8 regions represented in the model, each consisting of 8 to 24 districts.

The districts have the mandate to invest the budget in water infrastructure. The districts can invest in three categories (Assumption 8). Districts determine what ratio of the budget that they receive from national level they invest in what category. Districts are assumed to spend all available budget on the category, without considering the status of their infrastructure (Assumption 10). The categories are called X, Y and Z and represent the following:

X: budget for Capital Expenditure (CapEx). CapEx is used to construct a new water point. Installation of a new water point includes the construction of a shallow well and the placement of a hand pump on the well. National level dictates that at least 70% of the budget is to be spent on CapEx.

Y: budget for Capital Maintenance Expenditure (CapManEx). This is used for major repairs of water points. A major repair represents the complete replacement of a hand pump. Similar to the conditions in the grant at the most 13% of the budget may be spent on CapManEx.

Z: budget that remains unspent in the financial year. It is assumed to be returned to national government.

The amount of budget that a district receives is based on an allocation formula [Ministry of Water and Environment, 2013a]. In the formula, however, there are some ambiguities that make implementation of the formula in an ABM difficult, it is for instance not clear how much budget districts that perform above the national average performance receive. Therefore the budget that districts receive is assumed to be similar to the actual budget received in Financial Year 15/16 [Ministry of Finance Planning and Economic Development, 2016] and is assumed to gradually grow with the same rate as the rural population growth over time (Assumption 9). An investment of a district in CapManEx represent the complete removal of a hand pump and the installation of a new hand pump (Assumption 6). A water point that is non-functional for a period of 5 years in a row is considered abandoned (Assumption 7).

#	**Content of the Assumption**
1	National government has infinite budget
2	Residual budget at district level is returned to national level every year
3	Districts are all the same in terms of possibilities created by geographical characteristics
4	All water points in the ABM are shallow wells operated by a hand pump
5	Failure of a water point is normally distributed with a mean of 6 years and a standard deviation of 1.5
6	A major maintenance operation of a water point entails the complete replacement of the hand pump
7	A water point that is non-functional for a period of 5 years is considered abandoned
8	The allocation ratio is composed of three factors: X (ratio of CapEx), Y (ratio of CapManEx) and Z (ratio unspent budget)
9	The budget allocated to districts is based on the actual budget in Financial Year 2015/2016 and grows with the same rate as the population growth
10	Districts spend all budget without considering the status of the infrastructure in their district

Table 1. Overview of Assumptions in System Conceptualisation Phase

4.2 Encoding Social Learning

The part above describes the necessary abstractions from the rural water supply system in Uganda. Given this conceptualisation social learning processes are implemented using the theory of memetics. The policy that district level can make a decision about is the allocation ratio. There are two degrees of freedom in the decision about the allocation ratio: X and Y. The ratio for Z is the result of choices made for X and Y. Following the theory of memetics the allocation ratio becomes the subject of analysis, i.e. the *meme*. To understand the process of cultural evolution that is described by memetics, we must consider the meme in terms of *fitness* with its environment [Heylighen and Chielens, 2009]. A meme that is sufficiently adapted to its environment is more likely to be propagated than one that is not. The process of *selection* determines how fit a meme is to its environment.

The Selection Process In the process of selection the fitness of an allocation ratio, the *meme*, to its environment is determined. This means we must determine how to measure the fitness of an allocation ratio in the rural water supply system and therefore we turn to how progress is measured in the sector itself. Progress in the Ugandan water sector is measured in water service levels. In Uganda four different indicators for water service levels are used: water quality, water quantity, water reliability and water accessibility [Biteete et al., 2013]. Consider a situation where an allocation ratio results in relatively high water service levels in a district. This allocation ratio can be considered a *good* or *effective* ratio. Consequently, a ratio can be considered *poor* or *ineffective* when it results in relatively low water service levels in a district. However, in the current conceptualisation of the rural water supply system not all of these indicators can be measured with the same ease. The water service level in the ABM is *water quantity* (Assumption 11). This choice is made as it reflects three out of four performance indicators that are used in Uganda and the indicator fits in the current conceptualisation of the sector described in the previous section. Districts are assumed to have full information about the state of the water infrastructure in the district (Assumption 12).

The performance of an allocation ratio is measured in the water service level of the district that applied the ratio. It is easy to imagine that higher water service levels are considered better than lower water service levels. However, the selection step considers what ratios are fit in their environment and what ratios aren't, in other words: what ratios are replicated and live on and what ratio are not replicated and grow extinct. Therefore we need an indicator of a *good* and a *bad* allocation ratio. This is done in two ways. First, the districts are ranked according to their performance measured in water service levels. A list of the districts is constructed based on the water service level - water quantity - they deliver in their district. Districts are ranked highest to lowest water service levels. This represents two mechanisms that we can observe in practice. First, districts observe and ask how other districts are performing. If a difference of 20%-30% in performance occurs, a district tries to imitate the policies or structures used by the other district. Second, the ranking provides an efficient method to stimulate performance. For the second method to separate good from bad allocation ratios national standards in the sector are considered. The national goal for target quantity is 20 litres of water per person per day [Biteete et al., 2013]. The two combined lead to the following consideration of a *good* allocation ratio: an allocation ratio that leads to a water service level in the district that is above the target quantity of 20 litres of water per person per day AND is ranked in the top half of the district ranking. Consequently an allocation ratio that result in a districts water service level below the target quantity OR in the bottom half of the ranking is considered *poor* (Assumption 13).

The Replication Process In the replication step is decided what allocation ratio is replicated and which districts replicate a ratio. In the selection step good and bad ratios are distinguished. This distinction is the basis of the replication step: good allocation ratio can be propagated, i.e. they can be spread to other districts. Bad allocation ratios are not propagated. This means that a district with a bad allocation ratio is assigned a new ratio. The ratio they choose is determined by the best performing district within sight. The meaning of *within sight* is described further on in this subsection. All districts that perform well use the same allocation ratio in the next time step. This represents the idea that the meme lives on (Assumption 14).

Districts that used an allocation ratio that is consider bad, replicate an allocation ratio from another district to use in the next time step. They are assumed to replicate the allocation of the best performing district within sight. The sight of the districts is based on the governance levels in Uganda and the different ways in which districts communicate with each other - the learning structures: inter-district, regional and national. These three scales of communication are applied by three conditions in the ABM. The national learning structure corresponds with the fully rational replication method, the regional learning structure with the myopic replication method and the inter-district structure with the random replication method. The method and what they represent is described below (Assumption 15).

Random: a district only communicates with one other district that is randomly selected and replicates the ratio of that district. This district does not have to be a neighbour. The random option represents inter-district communication, where representatives of two districts exchange ideas with each other.

Myopic: districts have limited information, they only have information from the districts in their region. They replicate the ratio of the top ranked district in the region. This situation represents regional exchange between districts. At regional level a variety of venues, e.g. learning fora, district come together to share best practices with each other.

Fully rational: district have full information about all other districts in the country. Therefore the districts replicate the ratio from the district at the top of the national ranking. This represents a situation where information is known and shared nationally. In the rural water supply sector in Uganda this represents the cycle where a district learns an effective policy and this is recognised by the regional level. The actor at regional level monitors progress and, if the policy indeed turns out to be effective, shares this knowledge with national level. National level in turn can make the policy mandatory for all other districts.

The Variation Process In the variation step the ratios are varied. The variation step provides two possibilities once a ratio is selected: make a perfect copy of the ratio or slightly adjust the ratio. In case of the second condition, the districts *move* from the ratio they used in the previous year to the ratio they are assigned to use in the next year (Assumption 16). The variation step in this research represents two different processes: an unconscious variation of the policy and a conscious action to change the policy. The unconscious variation is very similar to the variation process in genetics. Species reproduce themselves by making perfect copies of themselves. The process of copying, however, is not flawless and occasionally mistakes are made. This process is most determining in evolution. The 'mistakes' can turn out good, e.g. the development of an eye that enhances survival chances of a species, but is most of the times not beneficial to the offspring. However, if this process is repeated on a massive scale, over an enormous time span, we can understand how species gradually evolve to a variant that is more fit to the environment.

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Concluding, variation of a ratio that is replicated from another district can represent two things in practice: firstly, a communication or interpretation error. Second, the assumption that a district adapts the policy from another district to their own situation before implementing it. The conscious interpretation of variation is implemented by a one-year memory and the unconscious variation is added by the addition of randomness to the movement toward the other ratio. This leads to the following two scenarios in the variation step:

1. **Perfect copy:** the districts blankly imitate the ratio they have selected.
2. **Random fractional:** districts move a random fraction from the ratio that the district used in the previous year to the selected ratio.

In this subsection a conceptualisation of learning in the Ugandan rural water supply system is presented. Districts can learn from each other what allocation ratio they should use to reach relatively high performance. In the process of learning the allocation ratio is the subject. The ratio evolves through the system, following the processes of selection, replication and variation.

#	Content of the Assumption
11	The water service level in a district is measured in litres of water per person per day, aggregated at district level
12	District have full information about the state of the infrastructure
13	Allocation ratios are selected based on a ranking and on the nationally set target water quantity
14	Allocation ratios that are considered bad are not replicated, i.e. they *cease to exist*. Good allocation ratios are replicated, i.e. they *live on*
15	Districts replicate another ratio when they are performing poor. The ratio they replicate is the ratio of the top ranked district under the conditions of fully rational, myopic and random
16	When districts replicate an allocation ratio from another districts, they vary the selected ratio by making either a perfect copy, or adjust the ratio with a random fraction between the selected ratio and the ratio used in the previous year

Table 2. Overview of Assumptions made in the process to encode social learning using the theory of memetics

4.3 Experimental Design

Social learning is conceptualised and implemented using the theory of memetics. In memetics evolution of information is described through the processes of selection, replication and variation. The theory is applied by identifying a *meme*, a piece of information that could evolve, in the rural water supply sector. This meme is the *allocation ratio* that districts use, representing a policy choice at district level. The processes of selection, replication and variation enable to see an allocation ratio evolve through the rural water supply system. The experiments focus on different conditions for the evolution of the allocation ratio and therefore different ways of learning in the sector.

The experiment is set up using the processes of selection, replication and variation. All different methods are combined with each other into a set of scenarios. The experiment tests if different methods for replication and variation result in different system behaviour and different water service levels in the rural water supply sector in Uganda. The process of selection is implemented in a single way: a district ranking combined with a threshold value for good performance based on the water service level of a district. In the replication process three methods are described: fully rational, myopic and random. There are two methods for the variation process: perfect copy and random fractional.

An overview of the experimental design is shown in Table 3. However, as can be observed in the table, the matrix does not lead to 6 different experiments as one would expect with 3 times 2 methods. The implementation of the random replication method in the ABM is done in such a way that a district chooses an allocation ratio from a random other district. Adding or not adding a random amount of variation to this random process does not lead to different outcomes and is essentially the same. Therefore, the two variation methods for the random replication method are considered to be one scenario.

Variation method / Replication method	**Perfect Copy**	**Random Fractional**
Fully Rational	Scenario 1	Scenario 2
Myopic	Scenario 3	Scenario 4
Random	Scenario 5	

Table 3. Experimental Design

In total a number of 500 simulations are run with the ABM, a hundred simulations for every scenario. There are stochastic processes in the model, such as water point failure or the initial allocation ratio of the districts, meaning that multiple simulations of the same scenarios are needed to be confident about the average behaviour of the system. The simulations are ran using the *Behaviour Space* function in Netlogo, open source software for Agent Based Modelling [Wilensky, 2016]. Behaviour Space is an environment to set up simulations and determine output variables.

4.4 Results of experiments

In this subsection the results of the experiment are analysed. The section shows what we can learn from the different scenarios for learning. First the general behaviour of the districts in the ABM is presented.

General Model Behaviour In first instance we look at the general behaviour of the simulations. We are interested to see what patterns emerge from the interactions between the agents in the ABM. The model behaviour is expected to behave stable at district level, as the financial allocation from national level to district level is assumed to grow with the same rate as the population growth. The behaviour that is expected is stable in the sense that the districts reach a certain attractor value, where an optimal balance between investments and infrastructure breakdown is found. To observe general system behaviour a visualisation is made that shows the average performance of all districts for every simulation. This is shown in Figure 1.

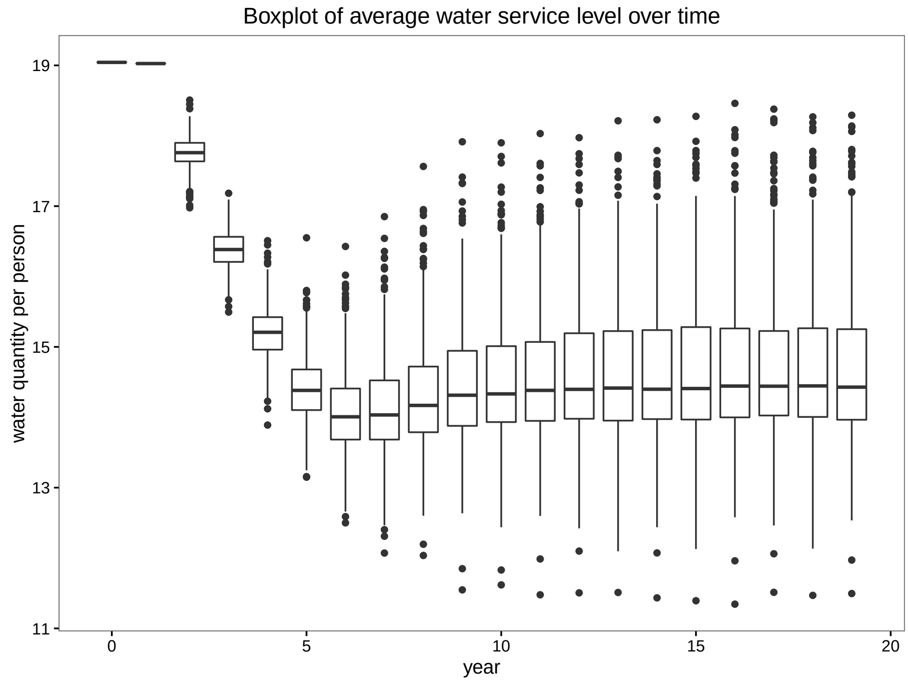
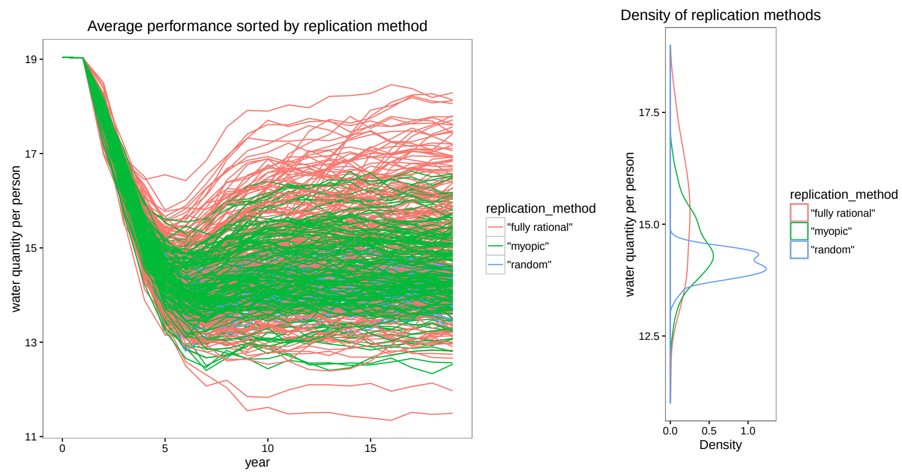


Figure 1. A box plot of the general system behaviour showing the average performance of the districts in 500 simulations

The figure is a box plot showing the average performance of the districts in all simulations. What we see is that in the first 5-6 years the average performance of the districts in all simulations shows a steep drop from about 19 litres of water per person to on average about 14 litres of water per person. The stable behaviour can be extrapolated over a long period of time. Extra simulations are performed that show stable behaviour over time in all simulation up to a period of 100 years. The steep drop is not a behaviour that is expected in the ABM. The steep drop is not an artefact of the implementation of the system in the ABM. The analysis shows that the drop is caused by the functionality percentage of the water infrastructure and thereby an argument is provided about the type of policy insights that can be generated with this method of analysing social learning processes.

Scenarios for Memetics In this paragraph the analysis of the scenarios for replication and variation are described. We first analyse the replication method, next we turn to the variation method. After that we return to the five scenarios for the interactions between replication and variation methods.

What would happen with the general system behaviour under different methods for replication? We have seen that all simulation runs follow a similar drop. We also have seen that the level at which the simulations become stable is spread over quite a range. A fair suggestion is that the replication method has influence on the level at which the performance stabilises. There are three methods: random, myopic and fully rational. They all represent a structure of learning that is observed in the rural water system in Uganda. The random method represent the scale of inter-district learning, the myopic method represent the scale of regional learning and the fully rational replication method represent learning at a national scale. The hypothesis is that the fully rational learning structure is resulting in better performance, as policies are spread over a larger scale. However, this also means that a bad policy can be spread quickly. The hypotheses is that even though the average performance of the fully rational method is best of the three methods, it might also cause some of the worst runs. The random replication method is assumed to perform worst, as the learning processes are at a low scale and districts choose a district at random. The myopic method is assumed to perform somewhere in between the two. Similar considerations as the fully rational method can be done, however, the policy spread is contained to the boundaries of the region. Average performance on a national scale, therefore, is assumed to be more in balance. The different replication methods are visualised in Figure 2a.



(a) Performance coloured by replication method

(b) Density of runs after 20 years

Figure 2. Average performance delineated by different methods for replication. The left shows all runs, coloured by the various replication methods as shown in the legend. The right shows the density of the runs that end at a certain water quantity level at the end of the simulation.

In the figure we see the simulation runs again, but this time coloured. The runs are coloured according to the replication method that is used in the run: red for the fully rational method, green for the myopic method and blue for the random method. What we see is that there is a concentration of myopic runs in the centre of the range. The random method is hardly seen. At the top and a few runs at the bottom, the extremes, we see some simulation runs with the fully rational method. As the output of the simulation runs overlap each other, we need a second figure to support this one. In Figure 2b a density plot is shown. The plot is a continuous function that is fitted on the end values of the simulation runs. In other words, all simulations end up at a certain water quantity level. If more runs end up at the same level, the density plot shows a larger deflection of the y-axis.

The combinations of the graphs confirm our hypothesis. First of all, the fully rational method seems to result on average in a higher national average water quantity of the districts. The fully rational method furthermore, also shows some really bad outcomes. The myopic replication method is similar to the fully rational method, but the effects are less big. This is caused by the fact that policies are spread over a smaller area. In a single simulation, certain regions can spread a very bad ratio and other a really good one and the effect will be average, whereas in the fully rational method these effects might be more influential. The random method shows some interesting behaviour. In the second plot, we can see a very stable behaviour of the simulations runs with a random method. None of them perform really well, relatively, and none perform really bad. All runs end between a level of 13 and 15. However, we miss some statistical information that we can use to support the argument in favour or against our hypotheses. Therefore another figure is drawn, shown in Figure 3.

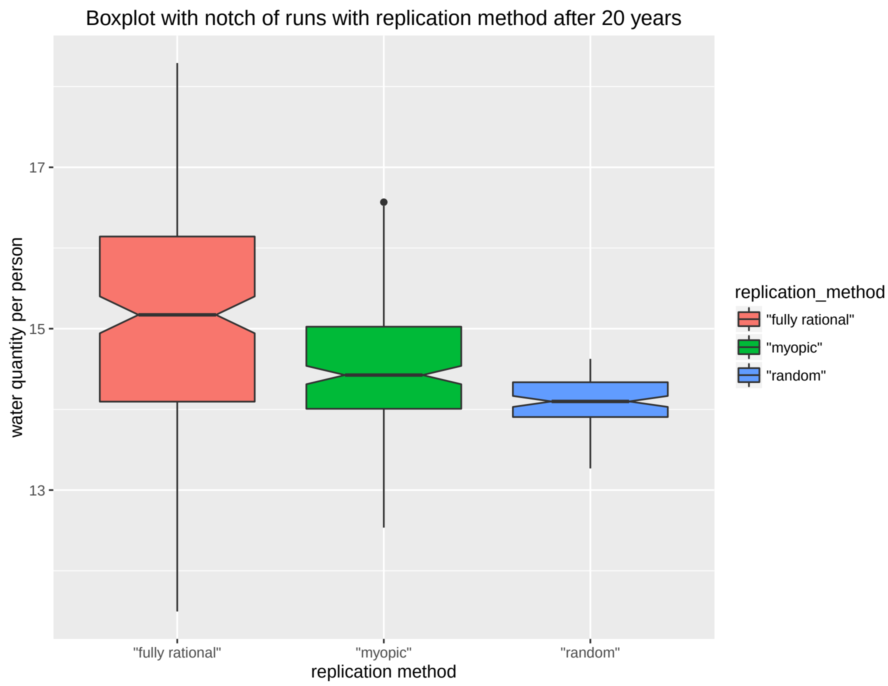


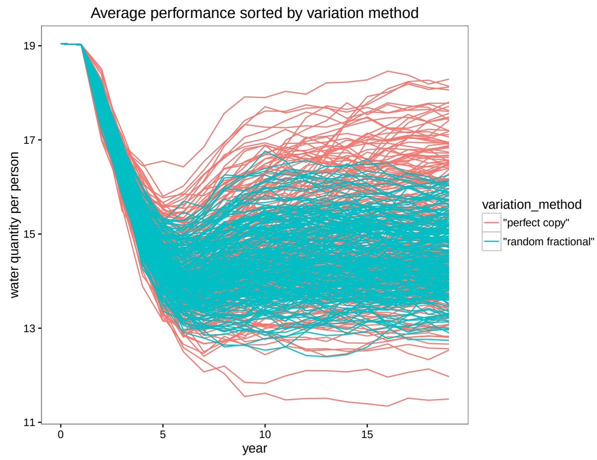
Figure 3. A notched box plot of replication methods

In the box plot we see another visualisation of where all simulation runs end up, i.e. the level at which the runs stabilised. Coloured by the replication method used in a similar way as coloured before. The notch in the middle of the box shows the 95% confidence interval of the median of the box [Mcgill et al., 1978]. The fully rational replication method performs significantly better than the myopic method which in turn is significantly better than the random method. We can conclude this as the 95% confidence intervals of the median of the plots to not coincide with each other. A second observation is that the spread of the outliers is large in the fully rational method and declines the smaller the scale of communication in the learning structure that is represented. The hypothesis of a larger spread is therefore confirmed. The outliers in the fully rational method are caused by the fact that the ABM is sensitive to initial conditions, i.e. a district that performs well and has a very good allocation ratio (e.g. zero unspent budget) is spread over at least half of the districts in one year time. This allocation ratio is then likely to survive over time, as also the best district keeps on performing well with a good ratio. The initial conditions of the districts, including the initial allocation ratio, is determined on a stochastic basis. The effect of a worse or good initial conditions is contained to a region in the myopic method and has almost no effect in the random replication method, hence, the spread of the outliers declines.

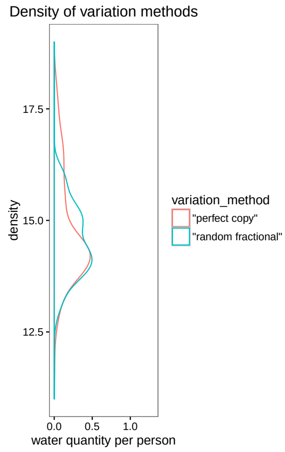
If we interpret these result we should first consider that the learning scales in practice are used in parallel and on different time scales. Image that the national learning structures take up more time than the regional and that the inter-district learning structures is used more often than the quarterly or monthly regional learning venues. What we can see by means of the simulations with the ABM is what the learning structures in an isolated way would result in. At this point policy makers in Uganda should discuss their goals regarding national policies on rural water supply. These figures support the considerations: if you aim for more stable performance, make sure districts randomly meet each other and learn from each other. If you aim for radical improvements via the national learning structure, be aware that the consequences are greater and that they can turn out negative as well. A more contained version is found in the regional learning structure.

We now consider the different methods for the variation process. There are two options for the variation method: in the first method the districts make perfect copies of their replicated ratio and in the second method the districts slightly adjust the selected ratio. The hypothesis is that the *perfect copy* method results in more extreme behaviour, as extreme allocation ratios are blankly imitated. The *random fractional* method is expected to result in more moderate system behaviour, as variation is added to those extreme allocation ratios. The variation method is therefore very closely connected to the results of the replication method, as the scale of communication of ratios is determined in the replication process. The methods for variation in the simulations are shown in Figure 4.

What we see in the left figure confirms some of our hypothesis. Both the extremely good runs and the extremely bad runs are induced by the perfect copy method. The runs for the random fractional method seems to perform more moderate. If we look at the right figure, however, the conclusion is more difficult. The two density plots do not seem to avoid each other that much. They are close together below a water quantity level of 12.5. Then at a level of 15, they diverge a bit, more random fractional runs end up at that level and



(a) Performance coloured by variation method



(b) Density of runs after 20 years

Figure 4. Average performance delineated by different methods for variation. The left shows all runs, coloured by the various variation methods as shown in the legend. The right shows the density of the runs that end at a certain water quantity level at the end of the simulation.

it seems that these runs are spread over the higher levels in the perfect copy method. Some support of the notched box plot is given in Figure 5.

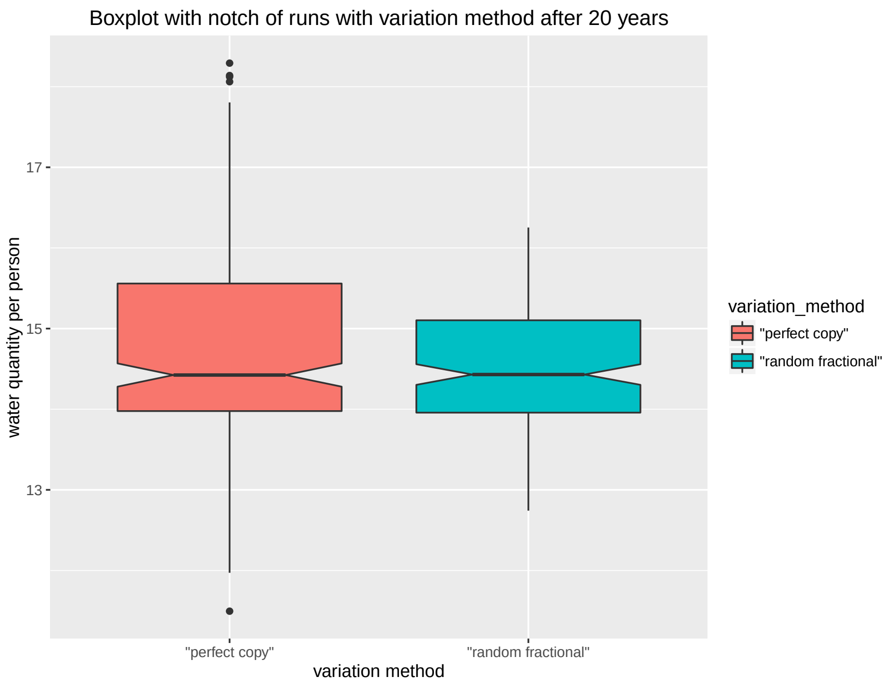


Figure 5. A notched box plot of variation methods

What we can see in the figure is that the medians of the two runs are similar. This means the runs on average perform the same and there is no significant difference between the two methods. Second, the outliers of the perfect copy method are spread over a much larger range than the random fractional method: 12-18 compared to 13-16. This could mean that is districts adapt a policy they selected to imitate, there are less extreme situations. A third concept to notice in the figure is the spread between the median and the 75 percentile in the perfect copy method. It shows that many simulations end up at these levels.

Reflecting on the insights here we could argue that the random fractional variation method performs better the the perfect copy method. The median is the same, but the spread is less, resulting in a more moderate performance, which seems desirable in the light of accumulating uncertainty and complexity in these type of systems. However, this is a choice of policy makers in Uganda. Do they either prefer higher service levels, accepting both a higher chance of good outliers and a higher risk on low outliers, or do they prefer a more moderate average behaviour? For this moment we conclude that the perfect copy method strengthens the conclusions about the replication method. The random fractional method reduces the effects induced by the different replication methods.

In this paragraph we have seen a standalone analysis of the difference in methods for replication and for variation, as well as a combined analysis represented by the five scenarios. The various scenarios for replication allow for Ugandan policy makers to see the isolated effects of a the three learning structures. The next step for the policy makers is to consider the goals of national policy regarding rural water supply and make more educated decision on the learning structures based on the output generated in this modelling study. An outcome of such a decision can for instance be to support certain learning structures more than other or to reconsider the time scale at which the structures are used. Another insight for policy makers in Uganda is to reconsider if the current institutional set-up allows these learning structures well enough in every region of the country. Regarding the different methods for the variation process we have seen that the interpretation very much occurs in the context of the replication method. The implementation of the variation method make that the methods either support the extremes of the replication method (perfect copy) or contain the effect (random fractional). The question whether it is better or worse to adapt a policy is difficult to answer. On the one hand we see that in the random fractional method the addition of variation to the policy ensures that changes in policy are not radical, as they on average stay closer to the current policy of the districts. On the other hand, we would expect that the conscious adjustment of a policy should result in better performance on average, but we don't see that reflected in the model outcomes.

5 Discussion

This research contributes to the understanding of encoding social learning in an ABM. In this research cultural evolution processes described by memetics enables to encode social learning processes in a water supply system. The notion of a meme as the subject of evolution in a multi-level governance system allows the analysis of the spread of policies through the sector. The necessary conditions for a loop of evolution - selection, replication and variation - force a modeller to make clear choices in the conceptualisation phase. One of the arguments for memetics is that the processes of selection, replication and variation would allow for a structured reflection of the applicability of the methods used in the ABM. For every step the use, the insights and a reflection on the core model assumptions for the part is given.

First, the selection process demands for an indicator of performance and an unambiguous definition of good and poor performance to determine what memes are selected to live on and what memes are considered less fit to the environment and cease to exist. A first reflection is that an indicator of performance that is supported and used by all actors in a system is not present in every system. In Uganda a variety of six performance indicators are identified: coverage, functionality, water quantity, water quality, accessibility and reliability. These are all used interchangeably by different actors in different contexts. A second reflection is that data on the performance of districts is crucial for this selection mechanism to work in practice. Encoding social learning using the selection step of memetics can generate insights about the measurement of performance in the system of interest adn the availability of data.

Second, the replication step provides the opportunity to consider and test different scales of learning processes. In the case study the replication process is used to observe the relation between the institutional levels involved in learning processes and aggregated system performance. Districts with poor performance replicate the ratio from the best district within sight. The different scales of the learning structures are represented by the scale of the vision of a district - random, myopic or fully rational. The replication step moreover enables to observe the relation between learning in a system and the output of a system. The case study shows the possibilities to capture different structures in the replication process of memetics and simulate the effect of the structures over a period of time to analyse system behaviour. Based on the case study we can conclude that the larger the scale of communication, the better the system performs and the higher the variation of the output becomes.

Third, the variation process is meant to describe how an actor can adapt a policy from another actor and adjust it to its own fitness landscape. we analyse the difference between simulations where actors did not change the ratio and simulations where the actors moved from their previous policy towards a newly selected policy. We observed that the interpretation very much occurs in the context of the replication method. The implementation of the variation method make that the methods either support the extremes of the replication method (perfect copy) or contain the effect (random fractional). The question whether it is better or worse to adapt a policy is difficult to answer, making it difficult to draw a conclusion about the absolute effect of the different methods for variation and what the methods represent. On the one hand we see that in the random fractional method the addition of variation to the policy ensures that changes in policy are not radical, as they on average stay closer to the current policy of the districts. On the other hand, we would expect that the conscious adjustment of a policy should result in better performance on average, but we don't see that reflected in the model outcomes. In reflection on the work we learn what might enable better implementation of the variation process of memetics. Better in the sense that understanding about learning processes can be enlarged with the variation process. In order to apply the variation method so that we can draw conclusions about the difference between a policy maker that makes the conscious decision to adjust a policy from another district to their own situation and a policy maker that does not, the variation method should include a state-action pair. A policy maker needs to consider the state of the own system (e.g. geographical, infrastructural) to the state of the area where the policy was considered successful. This allows for rational decisions about adapting a policy in the variation procedure by policy makers.

Furthermore, the research contributes to general understanding of social learning processes by encoding social learning. In the process of encoding social learning a modeller is forced to understand and recognise social learning processes and structures that enable social learning processes in a sector. In a multi-level governance environment these structures can be messy and identifying the structures and processes as well as describing the lack of clarity around them already adds value to the understanding of social learning in the system.

Where the process of encoding social learning can enhance understanding of the social learning structures in a sector, the actual encoding of social learning and the resulting experiments can create insight in the relation between social learning structures and output of the system. The case study shows the possibilities to capture different structures in the replication process of memetics and simulate the effect of the structures over a period of time to analyse system behaviour.

Next, the process of encoding social learning can lead to unexpected insights in the case study. The research demonstrates that by decomposing social learning and encoding the decomposed processes in a rural water system insight in the specifics of the system can be generated. In the Ugandan case study for instance extensive insight are gained in the effectiveness of current financial policies [Knipschild, 2016]. An example of a policy advice that generated in the Ugandan case study is that the current financial policy results in inefficient resource allocation. In the current implementation of the policy the district are dictated to spend a high ratio of their budget on investments in new infrastructure. This insights generated by this study argue that without this policy far better performance of the system can be expected.

A limitation of this research is about the representation of a policy in the case study. In the ABM we selected a meme as object of interest. The policy that determines on what districts spend the allocated budget from national government is enacted in the form of an allocation ratio. The allocation ratio is used in this research to represent how policies in general are spread through the rural water system. Therefore a reflection on the extent to which the allocation ratio represents policies in general is a logical step. The allocation ratio is a good representation of a policy, because every district implements the policy every year. This enables to analyse how such a policy spreads between all districts in Uganda. The ratio is also suited, because there are degrees of freedom in the policy. Districts can choose a ratio within the boundaries set by national level. This enables districts to learn what policy implementation of the policy works best for them.

However, a caveat can be placed with the allocation ratio. The relationship between a certain allocation ratio and output in the system is clear-cut. In practice we observe that the relation between a policy and its effect in the system is not as clear. This has to do with the similar representation of all districts and the choice for a financial policy. In this financial policy there is a clear direction on what is a 'better' way to allocate the budget, e.g. spend as less as possible on unspent budget, spend as much as possible on budget for maintenance. This guideline can be used for every district. In practice the relation between the policy and its effect in the system differ from district to district, depending on specific environmental variables in the district. A replication of this study using the processes memetics on one or even multiple policies that is/are heterogeneous in the output they generate amongst the various actor can complement to out understanding of the possiblities to encode social learning processes in an ABM with memetics.

The governance situation in Uganda is characterised by the presence of multiple institutional levels and dispersed decision-making. The levels reach from national level to community level. In the application of learning only the higher institutional levels in Uganda, i.e. district, regional and national level, are abstracted. This has implication on for instance the representation of geographical factors and the variation in water infrastructure that can be observed in the lower institutional levels. Another example is that failure of water infrastructure is encoded in the ABM by means of a distribution function, whereas in practice there are many dynamics influencing the failure of water infrastructure. The choice for scope was made to understand social learning processes at higher institutional levels, but only allows for analysis of aggregate system performance without considering the specific causes. The loss of the specific information can also be seen in the representation of a policy as discussed in the previous paragraph. Information that make districts different from each other is lost in the conceptualisation and this is exactly what is needed to analyse the spread of policies with a less clear-cut relation between policy and output.

In this research memetics is applied and encoded on one specific system: rural water supply in Uganda. It would first of all be interesting to see how this implementation performs in other, similar rural water supply system. This adds understanding to the possibilities for encoding learning with memetics and the type of insights it can generate in systems such as rural water in Uganda. Second it would be very interesting to see an similar implementation in a whole other system. This can be urban water supply, but it would be interesting to see how memetics can be applied to systems in other countries and what the possibilities are for memetics in sectors other than water. We can advance our insight into the applicability of memetics as a method to understand learning in a system and what types of insights can be generated given characteristics of the system of interest.

6 Conclusion

This paper contributes to research into encoding social learning in an Agent Based Model by describing social learning processes as processes of cultural evolution. Social learning is encoded by the processes of selection, replication and variation that are based on the theory of memetics. First, the process of encoding with this method contributes to the understanding of the possibilities to encode social learning and contributes to understanding of social learning processes in the system of interest. Second, encoding social learning with memetics in an ABM can generate useful policiy insight in the system of interest.

Recommendations for further research include addition of lower institutional levels. The hypothesis is that modelling lower institutional processes can enhance the understanding of the applicability of memetics for the purpose of encoding social learning. Furthermore the research can be complemented by a replication of the method with a meme that has an heterogeneous relation with the output it generates among actors and by application of the method in different (rural water) systems.

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