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TITOLO TESI

Commons-based Governance under uncertainty: the role of behaviours and information.

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How do people make decisions when the conditions for the economists' global rationality are not met (or even when they are) – remains an active frontier of research even today.

– Herbert A. Simon (1996: 371)

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Content:

Acknowledgment

Abstract

Effective irrigation water governance is crucial to address the future and sustainability of food systems. Limits to the governance of water resources for primary production are becoming more evident and complexity, uncertainty and human dimensions are receiving more consideration. To address these phenomena community level and collective actions issues are emerging as the most appropriate domains of analysis. In fact successful management of a shared resource largely depends on coordinated action at individual level that will reduce sector vulnerability at macro level. But cooperation can be at stake when unpredictable and rapid changes occur, thus undermining the capacity of community resiliency and adaptation. Despite the literature there is still lack of understanding concerning successful and constrains factors enabling cooperation under water changing conditions. To contribute the debate on how cooperative behaviours are affected by uncertainty and dig deeper in socio-ecological systems interactions, we propose an agent-based model integrating water resource uncertainty, cognitive processes and social behaviours into decision-making. We identify experience, access to information, reciprocity and network as factors supporting cooperative behaviours of resource users under water changing conditions.

Una efficace governance dell'acqua di irrigazione è fondamentale per affrontare il futuro e la sostenibilità dei sistemi alimentari. I limiti alla gestione delle risorse idriche per la produzione primaria sono sempre più evidenti e complessità, incertezza e comportamenti umani ricevono sempre più considerazione. Per far fronte a questi fenomeni la comunità e le azioni collettive stanno emergendo come i domini più appropriati di analisi. Infatti la buona gestione di una risorsa condivisa dipende in gran parte da un'azione coordinata a livello individuale per ridurre la vulnerabilità del sistema a livello macro. Ma la cooperazione può essere in gioco quando si verificano cambiamenti imprevedibili e rapidi, minando in tal modo la capacità di resilienza e adattamento di una comunità. Nonostante la ricerca nel settore manca ancora la comprensione su fattori che favoriscono o limitano la cooperazione in condizioni di variabilità di una risorsa come l'acqua. Per contribuire a tale dibattito la presente ricerca si interessa a come i comportamenti cooperativi sono affetti dall' incertezza e della conseguente interazione con i sistemi socio-ecologici. A tal fine proponiamo un modello che integra incertezza delle risorse disponibili, processi cognitivi e comportamenti sociali nel processo decisionale. Identifichiamo l'esperienza, l'accesso alle informazioni, la reciprocità e la rete come fattori di supporto a comportamenti cooperativi per utilizzatori delle risorse idriche in condizioni di incertezza di disponibilità.

1 Introduction:

1.1 Water users are agents of change

Water resources sit at the base of all social and economic activities and of ecosystem functioning and are of paramount importance for human sustainable development (WWDR4, 2016). Today water resources are exposed to great pressures from an increasing population and rapid urbanization. Thus resulting in a growing demand of water for productive, industrial and civic consumption. Yet this growing water demand needs to cope with variability and changes caused, for example, by the influence of climate phenomena and this is particularly true for arid and semi arid regions (Vörösmarty et al., 2000, IPCC 2014). Yet how this situation will reverberates on society its functioning and its interaction with the ecological systems is far from being understood.

Data available show that already 1.2 billion people are affected by water scarcity, defined as the lack of water to meet the demand for human activities. In 2025 water scarcity it is expected to impact 1.8 billion people, with phenomena of both *economic water scarcity* and *physical water scarcity* (FAO, 2007). The former defines a trouble in accessing water sources due to lack of infrastructure, while the latter one describes the lack of water availability. Some analysts estimate that water scarcity will increase water conflicts in the future. But history has been studded by water conflicts (Water Conflict Chronology map, Pacific Institute). Violence over water dates back nearly 5000 years with water as ancillary cause, but recent research over water conflicts found that there is an evolution of divergences with water at the centre of it. New trends highlight that interstate dispute are less likely than is cooperation, while there appears to be an increasing risk of sub-national conflicts among water users and competing economic interests, for which traditional mechanism of multilateral treaties are not as effective (Huntjens & Nachbar, 2015). As result the **micro context emerges as the relevant domain of analysis to address water management issues**. In this regard over three decades of common-pool resource empirical study suggests that managing resources, among which water, in the appropriate way requires to move the consideration of commons governance from the margins of state legislation or market perspective to local communities, their context, their institutions and behaviours (Ostrom 1992, Tang 1992, Lam 2001). This extensive empirical research has proved that community institutions and users collective actions can play a strategic role for socio-economic and environmental development when facing problems for example of water governance, of fishery or forest management.

Considering the case of water resources, self-governing institutions result capable to regulate water allocation among users, monitor violations and punish violators, to pool efforts to keep tube and channels clean and well connected to public infrastructures, to favour agreements among users in case of emerging of problems (as possible resource variations) thus enhancing resilience and sustainable development. These findings are further supported by the World Water Development Report (WWDR4, 2016). The report acknowledge the central role played by **water self-governing institutions and users as agents of change who affect and are affected by the water cycle and the rules in use**. The report stresses the need for collective action involving the diverse communities of users, suppliers and decision makers. Most importantly the report recognize the **lack of understanding of future social responses to unpredictable water variability** and support the idea that a collective efforts, in sharing knowledge among all the stakeholders, can help find ways to reduce the uncertainty, manage risk and overcome social dilemmas. Against this context the present work address this lack of understanding and knowledge gap in the attempt to contribute the study of the management of common water resources under uncertainty, recognizing users as agents of change and their institutions and micro-situational context as the appropriate level of analysis.

1.2 Community water management for sustainable food systems

To cope with a growing global population it is necessary to find solutions that can support a rising food demand in a world of finite and uncertain resources. Thus it is crucial to focus our research on the management of water resources for food production.

Water sits at the base of any productive systems and **agricultural water withdrawals accounts for 70% of all water used** by the agriculture, municipal, industrial and energy sectors (FAO, 2007). This data should be seen in combination with the fact that **in the world 80% of food is produced by family farms** (FAO, 2011). Coupling these two considerations provide the necessary evidence for this research to say that community is the appropriate level of analysis and that proper community water governance under uncertainty should be better understood to ensure equitable, efficient and sustainable governance and management of water for irrigation to achieve food security. Yet the connection was not clearly understood until very recently. In the following paragraph we highlight the fact that both the research field related to the economical governance of the commons and the one referring to the public policy science related to food policies converge in the consideration that collective actions problems should be better comprehended. The novelty introduced by this research is to pose the two fields in relation: how commons water governance under uncertainty can affect sustainability of food systems and food policies, and in return how food policy should start including uncertainty of water resources in their reasoning to shape robust and resilient solution towards food security.

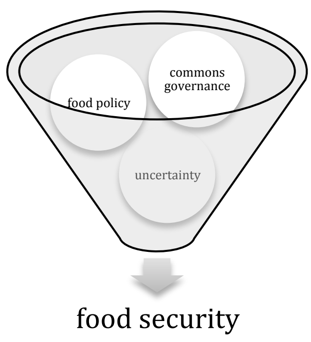

Figure 1 Research domains in relation to food security

In fact for most of the 20th the debate around food security unfolded around the *productionist* paradigm, focusing on growth and stability in the global food systems, considering unlimited resource availability. This approach certainly contributed to reduce famine and improve economic access to food (FAO, IFAD & WFP 2013) but did not succeed in responding food security and resource sustainability objectives. If Hardin (1969) with his Tragedy of the commons revealed the unsustainability of productive patterns of collective actions leading to the depleting of available resources, Morgan & Sonnino (2010) demonstrated, with the *new food equation*, that we have woken up from the prevailing perception of a world of food surplus to one of food deficit and social unrest, due to the spike of fuel, resources, food and energy prices. Further to this, it is interesting to notice that following research in both domains has led to focus on the community level as the principal scope of their investigations. Ostrom (1990) proved that collective institutions can successfully organize themselves for the management of common pool resources, while Sonnino (2014) identifies in lack of recognition of context-specific manifestations of global food system dynamics and of its micro perspective (i.e. household-level) the failure for the productionist paradigm. The two fields of research converged only recently by considering the interrelation of food systems with bio-geo-social and physical units, thus depicted as socio-ecological systems (SES) (Folke, 2006, Ericksen, 2008). SES are composed of multiple subsystems and internal variables, in which the resource system (water for irrigation) and the governance systems (organization and rules in use for water distribution and production) interact to produce outcomes at the SES level, which in turn feed back to feed these subsystem and their socio-economic and environmental components, as well as to other connected SESs. For the scope of the present work, looking at food system with this approach (Ericksen, 2008), allows to include water dynamics for irrigation in the equation, as this has not been done before and consequent question here is around self-governing institutions adaptability and policies that can support and favour the process of productive system resilience in spite of changing water conditions.

1.3 Complexity as an opportunity to understand water users behaviours

With regards to SESs, today a core challenge is to embrace complexity and resulting uncertainty and analyse different subset of interactions. Holling (2000) suggest that SESs complexity emerges not from a large number of interacting factors rather from a small set of localized processes and variables, these processes and variables being the essence of ecological, economic and social science theory. This exemplification allows keeping a degree of simplicity necessary for understanding and a sufficient grade of complexity to analyse this era of transformation and provide advice for the development of intertwined, adaptive and resilient policies able to cope with present challenges and collective actions. In this regard the present work is among the few in this domain and introduces process and factors to mimic and explore the effect of rising of social dilemma concerns with regard to climate change expectation on farmers' decision-making. The framework developed is characterized by:

- Simple representation of the social context in which symmetric farmers face a social dilemma in which short- term self interest (using as much water as possible) is opposed to community long-term interest (coordinate for a sustainable resource utilization).
- Dynamic and interdependent decision- making based on farmers' water demand. Farmers take a series of decision over time and repeatedly to achieve best available results, considering information available, their behaviours and rules in use. In fact an agency is also introducing policies (incentives) in the attempt to reduce free riding and improve water governance.
- Environmental variables as water variability over time.

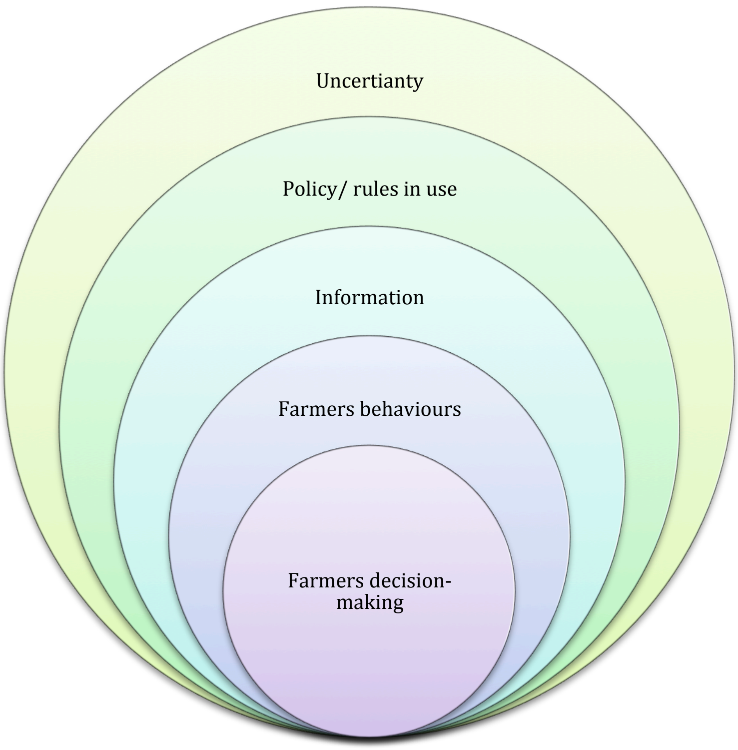

Figure 2 Framework of nested levels used in the thesis

The scope of this architecture is to embed uncertainty into the study of irrigation water resource governance. Considering the community level and the micro-situational variables the model aims to shed light on farmers decision-making given water changing condition and asses the effectiveness of policy in place in order to provide indication for future policy developments to sustain the transition towards adaptation and resiliencies of agricultural productive systems.

1.4 Research purposes and objectives

Given these considerations, in this thesis I investigate how information and behaviours, associated to incentives aimed at natural resource management, affect water users' decision-making with regards to the emergence of cooperation among farmers in spite of the uncertainty of water resources available. Central to this dissertation is to shed lights on factors and human behaviours that can enhance or constrain the emergence of cooperation and that should be taken into consideration for future intertwined water and food policy development scenarios. Selected factors are resource uncertainty, information and incentives. Selected human behaviours are the introduction of risk perceptions and reciprocity. These factors and variables have been selected because emerging as relevant from the analysed literature (see paragraph 2.3).

Studies have shown that cooperation is at stake when rapid changes occur (Dietz et al. 2003), that robustness of this type of SES is in danger facing spatial and temporal variability (Janssen et al. 2007) and that rainfall scenarios affects cooperative strategy convergence (Wijermans and Schlüter, 2014). Nevertheless we should incorporate in the analysis elements concerning behaviours of agents and consider the role that context based experience, reciprocity and risk aversion play in regards to strategic decision-making and cooperative behaviours. Accordingly there is a pressing need to identify factors and human characterizing behaviours that can enhance resilience under critical circumstances and avoid conflicts.

Toward this aim the main steps have been to:

1) Analysed a corpus of literature and methodologies to underpin the investigation. Choice fall on the governance of common-pool resources research to be explored coupling game theory and agent base modelling methods
2) Build a theoretical model of reference enabling the observation of phenomena and factors and gain experience in data analysis
3) Apply the theoretical model to real case studies in Puglia (Consorzio di bonifica della Capitanata) in order to explore the applicability of this methodological framework.

1.5 Reason for selection of case studies

Puglia Region the area of Foggia province and Southern Lebanon the area of Marjayoun are the two study areas looked at in this dissertation. They share a similar semi-arid climate and the projection of increasing dry days due to climate alterations. They are both key agricultural productive regions. The two areas differ for the present water availability condition; Marjayoun is already experiencing water scarcity, while the area of Foggia is not under this condition yet. The community governance system in place in Marjayoun area is based on Water Users Associations (WUAs), while Consorzio di Capitanata is the local participative institutional body in charge of drainage and irrigation water management. The first case offers the opportunity to study the robustness of self-governing institution if faced with uncertainty in arid, semi-arid regions thus to provide insight for the progress of the current integrated water resource management (IWRM) framework process. While the open question for the second case is about the future decision-making of farmers (members of the consortium) in case of resource variability. Both cases are functional to the analysis of the sustainability of existing cooperation among farmers in spite of water changing conditions and considering incentive, information and behaviours as possible influencing factors to sustain the local productive food system.

1.6 Dissertation structure

Having explained above the general nature of the intended research, the structure of the dissertation is as follows:
Chapter 2 illustrates the framework, it is intended to explain the conceptual and analytical framework in which the research is built: a review of commons dilemma issues under uncertainty introducing the concept of socio-ecological systems, the role of water institutions and the variables selected like uncertainty, information and behaviours to address water governance and human decision-making. In chapter 3 the methodological framework is illustrated, the use of Institutional Analysis Development Framework (IAD) and design principles and the dive into Game Theory and Agent Based Modelling to explain the reason for this methodology selection. The next chapters focus on the analysis and in chapter 4 the robustness of Lebanese water users association is explored, in chapter 5 results of modelling evolving scenarios of water institutions under uncertainties are described. In chapter 6 the obtained results are discussed together with limitation and possible future models extensions. In chapter 7 research conclusions are drawn.

1.7 Related publication

Tegoni C., Licomati L., (2016). The Milan Urban Food Policy Pact and the role of cities in localizing SDGs through the lenses of food (proceeding GMA-Politiche urbane del cibo, Torino 15-12-2016)
Tegoni C., Mulazzani L., Setti M. (2016), Water Governance under Uncertainty: the Case Study of Users Associations in Lebanon, New Medit, vol 15, n.1, (March 2016), pp. 62-71.

2 Theoretical and Conceptual background

Main challenge today is to embrace complexity. As such the analysis of complex system like socio-ecological ones requires making use of integrated concepts spanning over several disciplines. Community water governance issues to sustain food systems can be depicted with the lens of common-pool resources theory and the study of socio ecological systems. Behavioural economy and social theory allow us to introduce important processes and elements such as learning and reciprocity as well as information, to explore decision-making and interactions in a system under uncertainty. While game theory and agent based modelling offer means to encompass these theories and elements to develop scenarios and study emerging patterns. Multiple concept and terms used in this dissertation require clarification. The following sections define these terms and set the context for the study.

2.1 Water governance and self-governing institution of irrigation systems

Water Governance

In the literature the term water governance (WG) does not have one, all-encompassing definition. However, the concept is consistently distinguished from water management. Governance is the process through which water is managed. Water management includes the practical measures and tools used to distribute, develop, analyse, and protect water resources (Rogers and Hall 2003). Water governance describes the decision-making framework for water within society, the processes that design, implement, and ensure effective management operations (Simms and de Loe 2010).

The literature distinguish several WG 'regimes', typically divided into hierarchical, market, or network based categories, according to which institutions hold primary authority. Hierarchical, state-led governance provides a centralized government authority with clear management laws and vertical accountability lines for enforcement (Rogers and Hall 2003). However, market-state partnerships can provide an alternative decision-making method to stabilize an economy during rapid growth (Gleick 2000) or lack of governmental leadership as in the case of Lebanon where markets driven agents have replaced the central authority in the water governance and distribution due to a void in the political powers. Societal dissatisfaction with market or state governance regimes often forms a third, informal but important voice — the civil society or citizenry — demanding to take part in the discussion and decision-making and in many cases self-organizing in informal institutions like Water Users Associations. This decentralized governance type creates a framework for consensus-based, socially-acceptable decisions (Rogers and Hall 2003; Simms and de Loe 2010), which are often better suited to contemporary socio-political and economic issues. The latter is the object of the present study and 'water governance' refers to interrelation and emergent behaviours between a institution in charge of water governance and its final users, in this case the famers. Decentralized frameworks for water governance evolved as processes for multi-stakeholder decision-making that integrate social values, that filled the void left by central government in response to societal need to overcome resource related social dilemmas. Their incorporation into established WG frameworks is recent and the processes are still embryonic and confusing in comparison to the clear, formalized structures society is used to (Gupta, et al., 2013; Rogers and Hall 2003). In addition, to recent date, the existing systems are exposed to several challenges among which the variability of the water resources, that are happening faster and this has lead to a new front where state, market and users are faced with the uncertainty and the necessity to take strategic decision under a highly variable framework. Thus, for decentralized forms of governance to be effective, new challenges need to be resolved and solutions evaluated that focus on important elements of decision-making processes and shed lights on key factors to successful water governance to adapt to rapid changes.

Water self- governing institutions

Since 1990, the theory on Common-Pool Resources (CPR) investigates how to better design institutional rules to manage shared resources, that are subtractable and for which is not possible to exclude anybody from using it, like water for irrigation purposes, responding the treat of resource overuse leading to its depletion. This theory presents CPRs' users facing "social dilemmas". Social dilemmas are generally defined as potential conflicts between immediate self-interest and long-term collective interests (Van Lange et al. 2013), and they are recognizable in most of world's pressing problems especially in the environmental domain causing the incapacity to cope e.g. with climate change namely with reduced water availability in agriculture. In the conventional theory, CRPs' users are trapped in a "tragedy of the commons", unable to prevent processes of overuse and potential destruction of the ecological system unless regulated by the market or the state (Hardin,1969). Nevertheless progresses in this theory showed how users themselves could find ways to self-organize, to successfully manage shared resources through cooperation and participatory processes (Ostrom,1990). Furthermore empirical research, demonstrated how cooperative processes induce adaptive institutional changes to overcome social dilemmas arising from local natural variability (Ostrom, 1992; Tang 1992, Lam, 1988, 2001; Janssen et al, 2007). However recent findings indicate that these institutions can fail when rapid or significant changes occur (Dietz et al. 2003). In particular irrigation self-governing institutions effectiveness is increasingly conditioned and undermined by the instability of the socio-economic situation, by climate variation, and by the deriving repercussions on the irrigation systems (Anderies et al. 2011). In addition how collaborative behaviours can be compromised by uncertainty is still far from being understood, thus it is of paramount importance to address social and ecological factors in a integrated fashion to explore their role in influencing cooperation and decision-making in complex settings. In this regard factors and variables influencing cooperation and decision-making are gaining attention in the natural resource and management science (Polasky, 2011; Schlüter & Pahl-Wostl, 2007, 2010). Especially with regards to water resources (Pahl-Wostl et al, 2000; Wijermans & Schlüter, 2014) as managing irrigation systems to sustain food production of a growing global society is becoming an important challenge of our times.

Irrigation Systems self-governing institutions

Irrigation systems are exemplar cases of CPRs. Their functioning is subject to cooperation and coordination. The underpinning infrastructure needs to be properly maintained in order for the system to function and also this require the collaboration of all the actors involved in the system. Irrigation systems appeared 8000 years ago in the Middle East and independent development of irrigation systems can be found all over the world. An increasing demand for food has lead in the expansion of irrigated land in the past decades. In many part of the world (Africa and Asia) we observed complex irrigation systems in which lots of money has been poured for investment in top-down infrastructural interventions. These massive investments proved to be inefficient and not sustainable in terms of benefit after the project was completed. Ostrom reports several of these cases in her "Crafting Institutions for Self Governing Irrigation Systems" (1992). She warns against perverse incentives and stress the importance of understanding traditional systems already in place and thus to involve farmers organizations in the design, implementation and management of an irrigation project. At the end of the 1990s major donors recognized the importance of successful farmers organization behind efficient irrigation projects, exemplar is the case of Balinese "water temples" to manage irrigation Lansing (1987). Lansing proved that the foreseen technical and invasive intervention was leading to the worst result of destroying a long enduring and successful water eco-system governance developed by the local farmers.

Nevertheless today irrigation systems are under the spotlight in consideration of the increase of global population, that generates a growing food demand and lead to competition on available water resources between sectors. In this century irrigation systems need to improve their efficiency because most likely there will be no major investment in new irrigation plant as the most of the arable land is taken. Better insight should be gained on the governance of available resources and on coping with unexpected change in the state of the socio-ecological system. Development in this sector should be perceived as an integrated process of hard and soft measures including water governance and management options with an inclusive approach of all relevant stakeholders. To this extent science should provide evidences for future policy advance in the field.

2.2 The Commons from tragedy to self-governance

The commons Dilemma

Social Dilemma is defined as a human-group situation in which individual interests are at odds with collective optimal outcomes. The dilemma correspond to two possible type of decisions, on the one hand it is possible to opt for a choice that maximize personal interest and on the other hand, to cooperate and contribute with the group to achieve an optimal collective benefit, loosing part of own personal benefit. This implies a trade-off between personal and social benefits. Similar situation are characterizing the relation between nature and society in its several dimensions. If nature is supporting spiritual and material human life, human activities are building the environments. Any variation of nature can influence decision-making and collective actions, at the same time any construction by the society generates ecological responses in a complex loop of interconnections. It is largely recognized that human productive activities tend to overharvest the available resources both in stocks than in quantity and that the risk faced by human kind is the story of the Island of Pasqua, where the population disappeared for the complete depletion of a life-sustaining resource. But what leads people to a similar decision?

In the literature have been recognized several categories of dilemma. These are: a) Benefit-risk dilemma, which is the trade-off between the actions that bring individual benefits, but that entail risk as well. This is, to what level of risk is worth it to assume, in reaching certain level of benefits. b) A temporal dilemma, which is the dichotomy between short-term survival and long-term survival. c) A spatial dilemma, which has to do directly with environmental topics. It consists in weighting to what extent an individual should make decisions in order to assure local security, and contribute to conservation of regional and global resources. d) A social dilemma that is the decision between the assurance of self-survival and collective survival conditions. In sum, a cooperation dilemma in the environmental realm can be seen as a mix of the dilemmas mentioned above (Jager, 2000).

Another aspect of the structure of the dilemma is the perspective that an individual has on it. According to Vlek (1996, in Jager, 2000) a person who faces a social dilemma may not realize the situation he is in. There are four types of unawareness of the dilemma: a) The individual may not perceive that he could generate negative externalities to the society in the mid or long term, as a consequence of his short term decision. In other words, the person is not able to perceive the relation between his decisions and the negative collective outcomes. b) The actor may not be aware of the consequences of accumulation of externalities. c) The person could think that his behavior generates small negative collective outcomes in relation with the benefits. And d) the agent may know the social risk derived from his decisions, but he may think that it is uncontrollable, therefore this person can perceive himself being in a no-choice situation (Jager, 2000). Dilemmas are complex societal phenomena, therefore to address social dilemma in this investigation the decision was to formalize it as a theoretical game (Stag-hunt) in which self-interest is at odds with collective one to introduce the societal aspects in combination with a spatial dilemma of water resources variability.

The conventional theory: the tragedy of the commons

"Commons" refer to a way in which communities managed shared land in Medieval Europe. This land was not officially owned by any single individual, thus it was "held in common" from which the terms come from. Originally a set of rules was regulating the use of this common property and limiting its use to the members of a community. Therefore "Commons" refer to the land, the community and the set of rules that go with it to govern its use. The use of the term in the course of the history has taken a different meaning, it refers to a broad set of resources, forestry, water, fisheries which does not have a owner "open access" and that can be "shared". Immediately we can notice that there are no rules and no community of reference. This has generated phenomena of overharvesting of resources, because of lacking clear rules of use and mechanism to monitor and enforce those rules. The reflections on how best govern the commons has lead to a long debate in academia.

Already Aristotele back in the 350 BC shared his reflections on commons dilemma: *"…Property that is common to the greatest number of owners receives the least attention; men care most for their private possessions, and for what they own in common less, or only so far as it falls to their own individual share for in addition to the other reasons, they think less of it on the ground that someone else is thinking about it, just as in household service a large number of domestics sometimes give worse attendance than a smaller number.…" (Aristotle, Written c.a. 350 BC. 1977, Section 1261 b p 77).*

Hobbes noticed also in is parable of the man in a state of nature that: men seek their own good and end up fighting one another. But according to Poteete (2010), three are the works at the origin of the conventional theory about commons dilemmas : the tragedy of the commons (Hardin 1968), prisoner's dilemma (Rapoport and Chammah 1965) and the free-riding problem (Olson 1965). These theories influenced political decision and lead to the imposition of rules and land privatizations.

This dilemma is then well represented in the paradigmatic work of Garret Hardin the Tragedy of the Commons (1969), in which the authors provides explanation and possible solutions to overcome it. He used the example of a common pasture utilized by herders for feeding their cattle that illustrates how the degradation of the commons is the predictable outcome if each herder put more and more animals in order to fulfil his objective of individual benefits. According to Hardin, in absence of external rules and private property rights herders' behaviour will deplete the commons resource bringing poverty and leading to ruin. He wrote: "*Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all*" (Hardin, 1968, 1244).

Hardin concluded that two options could possibly resolve the tragedy. One option was to give the herders private property rights, in order for each individual to bear the risk of its choice in terms of depletion of its available resource. A rational choice farmer would choose to put only an appropriate number of animals. The other possible option is for a public authority to restrict the amount of resource that can be consumed and monitor the amount of resource consumed at its own cost. The importance of Hardin arguments lies within the applicability of this metaphor to many different environmental contexts. He suggested that people are not able to self-govern common resources. In the later part of the 1960s there was an increasing awareness of the decline of natural resources due to human activities and Hardin's observations have been widely accepted due to its consistency with prediction from traditional economic sciences with regards to examples

of depletion of environmental resources (acid rains and oil crises). Hardin's paper provided a simple set of solutions. To avoid overexploitation of resources shared in common it was critical for the state to either 1) establish, monitor and enforce private property rights or 2) directly regulate the use of the commons either by taxing or directly restricting its use.
The model of Hardin has often been formalized as a Prisoner's Dilemma (PD) game (Ostrom, 1990). In short, if each agent pursues her own interest, the game's outcome will be inferior to a scenario in which every agent cooperates and the game reaches the social optimum. Game theory has often been applied to depict a number of situations like a game. A game is a form of modelling strategic interactions and easily fits the representations of commons dilemmas. In particular the Prisoner Dilemma fascinated scholars for the capacity to depict the paradox that individual rational choice lead to collective irrational outcomes, challenging a strong believe that rational human beings can achieve rational results (Ostrom, 1990).
In the same years there was another important work by Mancur Olson, the *Logic of Collective Actions* (1965) investigating the difficulty of getting individuals to pursue their joint welfare. Olson identified three conditions that influence collective action; group size, heterogeneity, and selective incentives. The fundamental problem of collective action situations is that when individuals have to contribute to a collective objective, these contributions are concentrated but the beneficial outcomes are distributed and diffused (Poteete et al. 2010). Olson emphasized the role of incentives and the generation the free riding phenomena, as a pervasive potential behaviour of every actor in a collective action situation. Free riders enjoy the benefits of the cooperation effort of other actors in the group. Olson's logic of collective action predicts that it works only in small groups.
These models received wide attention for their capacity to capture important factors of different problems occurring in different settings, moreover they frame and picture easy-to-adopt solutions. Yet this frame is characterized by constrains, like perceiving resource users in the form of prisoners in a jail incapable to change their situation, and this frame as foundation for policies made the models dangerous, leaving out of the door many more variables and explicit base conditions. To this extent a great contribution to the theory of collective action was brought by the work carried out by Elinor Ostrom "Governing the Commons" (1990) and from which she became a Nobel laureate (2008).

The rise of an alternative perspective: Governing the Commons

The efforts Ostrom and other scholars poured into the collective action theory was to show that the conventional theory was simplistic. Through comparative analysis of real case studies they demonstrated the fact that communities can successfully self-govern their shared resources for a long time without private property rights or governmental interventions. Her work is grounded on a theoretical understanding of institutions, using a methodology she developed, the Institutional Analysis and Development (IAD) framework, described in a dedicated section and roots of the analysis of the cases presented in this research. This method allowed Ostrom to compile success and failure elements of the analysed cases (from fishery to forestry to irrigation systems) and brought her to see commonalities. In 1990 in her book *Governing the Commons,* she identified eight design principles that characterize successful self-governance strategies, including not surprisingly, cheap mechanism for monitoring and solving conflicts. These principles have held up to the test of time (Cox et al, 2009, Baggio 2014) and have been used to provide insight of the Lebanese water user association in the comparative study in this research.

In her study she also formalized a non-cooperative game describing an alternative solution not yet considered. The herders could make a binding contract themselves for a cooperative strategy to work out and share the cost of enforcing it. "Solution" of this game is for both herders to share equally the sustainable yield levels of the meadow and the cost of enforcing this agreement, so long as each herder's share of the cost of the enforcement is less than a fixed value. My research starts from this point and consequent questions are: until when the agreement can hold in spite of changing conditions? We will investigate the issue using the Lebanese water users associations' case and Consorzio di Capitanata case. Is the punishment the only incentive to cooperation or there are other factors that can support cooperative behaviours? Answer to this question will be searched by means of simulations with the help of agent based modelling techniques.

Yet Ostrom herself was already conscious of the limitation of a self-financed contract enforcement game and warns scholars that there is no blue prints solutions to the governance of the commons (Ostrom 2007). Commons are indeed complex systems; in which elements are interrelated in such a way that one element cannot be studied if not in relation to the others (Ostrom2007; Van Laerhoven, Ostrom, 2007). Several framework have been proposed to address complexity for the study of the commons and all agree on the importance of embed uncertainty, information, policy and behaviours to gain better understating of complex socio-ecological systems and its governance (Oatrom, 1995; Holling, 2001; Berkes et al., 2003; Ostrom, 2009).

2.3 Conceptual Framework

Social Ecological Systems (SESs) and complexity

Before entering the details of the methodology is important to introduce the characteristics of socio-ecological systems and its complexity to support the choice made for this research.

The term social-ecological systems (SESs) imply the notion of dependence and relations between society and nature. This concept has not been evident for occidental science during the last two centuries. However, since the ancient Greece, philosophers recognized this integration. Economists like Malthus acknowledged the environmental constraints of human population growth. Geographers and anthropologists interpreted culture, space and territory as a social construct shaped by the environmental conditions. Ecologists from Odum's school, and conservationists (Leopold 1949) focused on the impacts of society on ecosystems. Berkes and Folke (1998) coined the term "social-ecological system" to explain their perspective about the interactions between nature and humans, they expressed the concept as follows: "*We hold the view that social and ecological systems are in fact linked, and that the delineation between social and natural systems is artificial and arbitrary. Such views, however, are not yet accepted in conventional ecology and social science. When we wish to emphasize the integrated concept of humans in nature, we use the terms social -ecological system and social – ecological linkages.*" (Berkes & Folke, 1998, p. 4.)

Research organizations such as the Stockholm Resilience Centre include in its web site the following definition of SES: "*Social-ecological systems are linked systems of people and nature. The term emphasizes that humans must be seen as a part of, not apart from, nature — that the delineation between social and ecological systems is artificial and arbitrary. Scholars have also used concepts like 'coupled human-environment systems´, 'ecosocial systems´ and 'socioecological systems´ to illustrate the interplay between social and ecological systems. The term social-ecological system was coined by Fikret Berkes and Carl Folke in 1998 because they did not want to treat the social or ecological dimension as a prefix, but rather give the two same weight during their analysis.*" (Stockholm Resilience Center).

Several disciplines have been proposing integrating concepts in this field of research, like the integration of policy, economy, cultures and traditions. In particular ecological economics' field attempt has been in the direction of the integration of ecology and economics, conceptualizing the economy as a system included in the ecosystem. Contributions of ecological economics to a more integrative vision of the relation between society and nature is the use of a conceptual basis that rests in the general systems theory, neoclassical economics, adaptive environmental management and behavioural economics among other fields of knowledge (Costanza et al. 1997). Though ecological economics use some of the approaches and methodological tools of environmental economics, they are taken as one information sources among others, and their results are interpreted in a more integrated form with ecological and social contexts. What is relevant to record is that the field has shifted the focus from isolated parts of the system towards relations, structures and processes. This has been fully integrated in the present investigation and relations are introduced in the form of network while behaviours in the form of reciprocity and risk aversion to study humans-nature interactions to reach desired outcomes from their productive activities.

More recently Anderies (2004) describe SES as an ecological system intricately linked with and affected by one or more social systems. Where social simply means, "tending to form cooperative and interdepended relationships with others of ones' kind". The term SES thus refers to the subset of social systems in which some of the interdependent relationships among humans are mediated through interactions with biophysical and non-human biological units. An example is when one of the farmer's activities changes the outcome of another farmer's activity through the interacting biophysical and non-human biological units, in this case water. This notion introduced by Anderies restricts the attention to those SESs where cooperative aspects of social systems is key and individuals

have intentionally invested resources in some type of physical or institutional infrastructure to cope with diverse internal and external disturbances. With this perspective social and ecological systems are strongly linked and interconnected in an overall complex ad adaptive SES, that can involve multiple subsystem as well as being embedded in multiple larger systems. This approach leads to the definition of Socio-ecological Framework discussed in section 2.4.2.
This SES picture is including a variety of concepts and all of them are relevant when studying the trade-off between humans, economy and nature. Complexity emerges as one of the main aspect to be taken into consideration and it is the challenge researchers are facing today when studying the governance of coupled socio-ecological systems. The complex system theory assigns to complexity a place for its own, normally characterizing development in material living systems between order and chaos. It is interesting to look at SES with this perspective because it allows drawing fascinating reflections considering the role of information and networks in this research. For natural resources, complexity encompasses the diversity of ecosystem that produce the resource, but this complexity is confronted with the complexity of the culture that has developed resource's exploiting practices. The two systems are "adiacent possible" (Kaufmann 2000). They represent the sphere of possible actions, stimulating the rapid evolution, mainly observable between order and chaos (kaufman 2000). Kaufmann theorize that order appears as consequence of spontaneous self-organization of complex systems in which knower and known provide the impulse for driving profound transformation. This impulse is in reality a process of accumulation of successive useful variations, a process of learning in time and of the emergence of changing behaviours in a coevolving fashion. The vehicle of this transformation lies in the availability, storage and diffusion of information. This mechanism also appears to apply to the systems governing the commons (Berge & Van Learhoven, 2011). Berge and Van Laerhoven (2011) argue that self-organized adaptive systems probably will evolve more rapidly at the edge of chaos and raise creative adaptive solutions. They suggest scholars to embed inputs from complex system theory for future commons analysis. The point here is how to make self-governing institutions better evolver, to grant their capacity to be flexible enough to cope with uncertainty. In my research, which is no more than an initial exploration, I decided to follow this path. I recognize the existence of two "adiacent possible" of cultural (self governing institutions) and natural phenomena (water dynamics). I consider that there is lot of information available and that it can be possible to make use of it to foster the raise of collective innovative and adaptive solutions. Thus I decided to introduce a non linear ecologic dynamics of water, elements of behavioural economic, socio-organizational dynamics with a simple learning management routine and incentive based governance strategy in a growing network to observe success or constrain factors to the emergence of cooperation.

Human decision-making in complex SES system

Complex theory is also useful to support the modelling of human decision-making. Central to this dissertation are the strategic decision of farmers and their productive choice in relation to water expected and available. Traditionally, decision theory is divided into two major topics, one concerned primarily with choice among competing actions and the other with modification of beliefs based on incoming evidence. Our research focuses on both as they relate one another. A decision episode occurs whenever the flow of action is interrupted by a choice between conflicting alternatives. A decision is made when one of the competing alternatives is executed. The subject making the decision is optimizing is payoff and potentially nothing change in its limited living space. However in complex setting farmer's choice propagates in the ecosystems and can generate consequences on other players' choices and on the ecosystem itself. This resulting in a possible modification of the previous state of the system that in turn can alter our farmer future decisions. To this extent Poteete *et al* (2010) suggests that micro-situational variables, the broader context and the relationship between them are interrelated factors influencing collective actions in complex SES. The progress in the study of collective action and the commons in complex SES in fact moved from a vision in which all individuals are thought to be selfish and rational, with complete information on the system and the other actors' preferences including the full range of possible action and the probability associated with each outcome resulting from the combination of this actions, to a perspective of humans behaving not as selfish rational beings, that make decision with incomplete information and under uncertainty. This factors limit the extent to which rational utility theory holds and first Herbert introduced the concept of bounded rationality, that leads agents to choosing a solution that might not be optimal but that make them happy enough, following their satisfaction. Further studies (Fischebacher et al, 2001, Janssen et al, 2013; Janssen,2015) also observed that agents are conditional co-operators and look at others- preferences and that it is necessary to introduce behavioural perspective into the equation to gain better understanding on community resource management.

To summarize the equation for our analysis include uncertainty, information and behaviours as relevant factors that influence decision –making in complex SES. In the following paragraph I will explode this concepts.

Uncertainty, coping with not knowing

Uncertainty has different definition across domains and disciplines (see Walker et al. 2003 for a review) and can stem form different sources: epistemic (of knowledge and understanding), ontological (of the process themselves) and linguistic (communication and definition). Brugnach (2008) refers to it as "the situation in which there is not a unique and complete understanding of the system to be managed" and she argues that any uncertainty can be understood only in relation to the socio-ecological system in which it is identified.

Thus for the scope of this research uncertainty refers to both ecological and social uncertainty. Ecological uncertainty when water quantity is subject to variability e.g. due to the effects of climate change, this will help contextualize the SES. Social uncertainty, considering the micro variables, our agents in their baseline scenario are not aware of others' choice and outcomes of the choice of others.

Information to deal with unpredictability

The dynamic of an ecosystem can alter the information available to resource users, the state of the availability of the resource in the system and ultimately the decision of the users (Janssen, 2013). The dynamic of the social system can vary the information available to resource users and the state of the availability of the resource. In Consorzio di Capitanata as well as in the initial state of Lebanese WUA, water resource availability is known. Farmers expect to receive a defined amount of water. Nevertheless unexpected changes in the ecosystem can lead to an increase of dry days, thus in a variation of water resource quantity available for irrigation. This situation can generate an impact on farmers' decision-making and if it is the norm rather than exception new behaviours can emerge leading to a permanent change in the SES. In this description two interrelated kinds of information domains are recognized. They correspond to two knowledge frames, of natural and social system that can generate unpredictable outcomes (Brughach et al 2008). According to Brughach it is necessary to accept this situation of "not knowing" or "knowing to little" and to address the relationship between the different knowledge frames to elaborate flexible and adaptive solutions.

Thus for the scope of the research and to collect insights on the relation between these two information domain on water users actions, two type of experiment are conceived first the users will not have information on the system and on the other water users actions, secondarily they can access partial information that relates to outcome of the other players thus relaxing social uncertainty assumption.

Behavioural responses to water uncertainty

In the past 30 years behavioural economic has emerged as one of the most exciting field of study. The traditional utility theory of selfish rational behaviour could not explain some empirical observations, thus economists started relaxing certain standard theory assumption to increase the realism of their analysis and incorporating fairness, trust, risk etc (Cramer & Loewenstein, 2004). At the core of the new theory is incorporating psychological elements. This field has rapidly extended to the management of common resources and a more comprehensive framework including human behaviour is emerging (Janssen, 2015). In the domain of commons governance key elements are considered trust, conditional cooperation and reciprocity. Recent findings highlight that these elements are also influenced by social and biophysical context. Poteete et al (2010) suggest group size as micro- situational variable that influence behaviours, larger group will make more difficult to evaluate trustworthiness and incentivize free riding. Micro situational variable are also influenced by external context and under the threat of climate change how can group cope with collective action problems?

In this situation and for the scope of this research, the model evaluates the possible outcome of decision-making if information on the other players' actions is provided also against their risk perception. Incentive will be also assessed if influencing strategy choice of water users.

3 Methodological approach

For the scope of this research several methodologies have been used. Multi-method criteria have been largely adopted to study institutions' and small scale-irrigation systems' behaviours with the aim to gain understanding of their capacity of adaptation (Ostrom, 1990; Janssen and Anderies, 2013). In line with this approach case studies' institutional structure is analysed following the "action arena" concept included in the IAD framework and external elements thanks to the SES framework. Then their robustness, which refers to the capacity of a local institution to keep its own profile and mission (function, structure, feedbacks and therefore identity) when experiencing shocks, is assessed against the "design principles" defined by Ostrom (1990). Secondarily, GT and AMB are applied to investigate future evolving scenario of self-governing institutions under resource uncertainty. In this section we present a description of main functionalities of the techniques applied.

The Institutional Analysis and Development Framework (IAD)

Before entering into the details of IAD framework it is necessary to clarify the object of this theoretical framework. The framework is used to theoretically understand institutions.

Institutions are defined as the "*prescriptions that human use to organize all forms of repetitive and structured interactions*" (Ostrom, 2005a). The prescriptions can work at different scales from households to international treaties and in different context like in schools, hospitals, companies and irrigation systems. Prescriptions are of two broad types: rules or norms. Both rules and norms are crafted, recognized and agreed-upon by a group of people formally or informally. These rules or norms are not "written on stone" and any person can make choice whether or not follow the given rule or norm. As a matter of fact, choices and actions can have consequence for themselves or for the others. New rules or norms can be added in a relatively brief time, but changes or removal of rules is usually a slow process (Janssen, 2002)

The relation between institutions and individual behaviours that underlie economic activities, attracted the attention of a group of economist and social policy scholars, that proposed a new economic perspective – the new institutional economics (NIE)- beyond neoclassical economy, theorizing the role played by institution in influencing human behaviours (Coase 1937, Acheson 2006). Only in 2009 this new approach is extended in the field of natural resource management and CPR governance with the Nobel to Elinor Ostrom. Ostrom's IAD framework (1994, 2005) is in fact one of the academic developments inside the New Institutional Economics stream. In particular, in the CPR field, institutions design governance to relate with the environment (Ostrom 2005, Janssens 2002). Yet Ostrom recognized that the study of complex human situations required a theoretical tool to help translate implicit knowledge of do's and don'ts into a more consistent explicit theory and this is what the IAD framework is built for.

The IAD framework is aiming to guide the analysis for the understanding of institutions. It helps to identify variables and relationships needed to carry out the study and evaluation of institutional arrangements. The framework constitutes a meta-theoretical language for comparing structured situations. In fact Ostrom observed that regularized social behaviours are characterized by universal components and organized in different layers. In this way the framework contribute to dig below the diversity of social interactions in several fields like markets, elections or natural resource management and identify universal building blocks used to craft the institutions (Ostrom 2005). The situation depicted and the information collected can then allow comparison or be used in other theories. For example the components identified, thanks to the IAD framework, can easily depict the context in which a game is played and provide the information for game theorist. Other significant situations are to complex to be modelled with a simple game, and the information collected with the IAD can directly flow into a modelling tool, like agent based models, to capture patterns of interaction and outcomes in more complex settings (Janssen 2003). For the scope of the current work IAD had been use to draw a dynamic game with a game theoretical approach, while a more complex situation corresponding to the real case has been depicted with IAD and modelled with ABM.
Figure 2 illustrates the general framework of the IAD. Following the guidelines provided by Ostrom, the institutional analyst will first make an effort to understand the action arena, which is the Focal Unit of Analysis, leading to a particular pattern of interaction and outcomes. Then he should ideally zoom out and inquires into the exogenous factors that affect the structure of an action arena. In fact the action arena depends on a group of exogenous variables composed by three sets of variables: biophysical, community and rules. These three groups determine the action arena, which produces interactions that in turn generate outcomes. The outcomes, in turn feeds back the exogenous variables and the action arena structure. Outcomes could be evaluated by several criteria depending of the interest of the study such as: economic efficiency, equity, adaptability, resilience, and robustness, accountability, and conformance to general morality (Ostrom 2005). This step allows to see each action arena as a set of dependent variables and to move forward to see how action arena are linked together sequentially or simultaneously. Finally the institutional analyst should dig deeper and explore the action situation. The depth of the analysis and the capacity to observe several action arena depend strongly on the practice of the method.

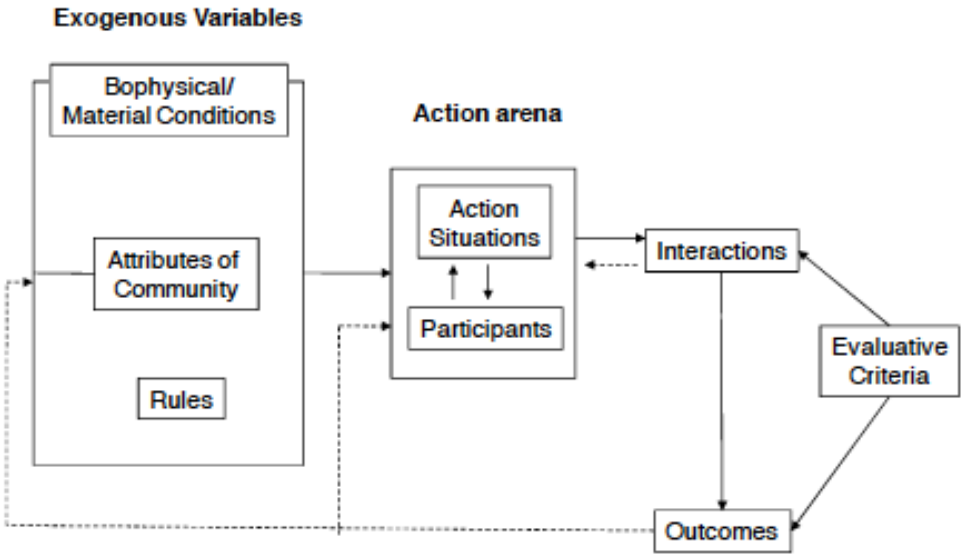

Figure 3 Framework for institutional analysis (IAD). Source Ostrom (2005)

The action arena

Central concept of the IAD framework is the action arena, which is the focal unit of analysis. When people use CPR withdrawing units (such as water, fish or timber) of the resource, they are in an action arena. In an action arena, participants, rules, norms and attributes of the physical world come together. The latter two elements, the rules and norms and the physical world are said to define an action situation. Action situations remain stable over time relative to the participants who may take part. As participants interact in the action arena, they are affected by exogenous variables and produce outcomes that, in turn, affect the participants and the action situation. Action situations exist in homes, neighbourhoods, regional councils, national congress, community forests, city parks, international assemblies, and in firms and markets as well as in the interactions among all of these situations. Evaluation criteria are used to judge the performance of the system by examining the patterns of interaction. The distinction between action arena and action situation is necessary. Action arena can include several action situations and participant can have different position in different in an action situations in the same action arena and this can lead to very different outcomes.

In the action arena participants are interacting in an action situation, which is affected by a broader context. As before mentioned the context is affected by three clusters of variables (1) the rules used by participants to order their relationships, (2) the biophysical world that are acted upon in these arenas, and (3) the structure of the more general community within which any particular arena is placed.

Different discipline may look at one of these three variables. Sociologist can prefer to look at community and culture, but for our scope, and in general economist focus more on the rules that affect the incentive of the participants. Action arena is important because it allows making assumption about participants and predicting outcomes. At this point if predictions are supported empirically that means that we have developed a good analysis. If predictions are not supported, as it is the case for social dilemmas, we need to dig deeper and to try to understand why, exploring nested sets of components.

In the action situation a participants occupies a certain position. The same participant can interact in another action situation with a different position.

The structure of all action situations can be described and analysed by using a common set of variables. These are: (1) the set of participants, (2) the positions to be filled by participants, (3) the potential outcomes, (4) the set of allowable actions and the function that maps actions into realized outcomes, (5) the control that an individual has in regard to this function, (6) the information available to participants about actions, outcomes, and the linkages between them, and (7) the costs and benefits—which serve as incentives and deterrents—assigned to actions and outcomes. The internal structure of an action situation can be represented as shown in Figure 3. In addition to the internal structure, whether a situation will occur once, a known and finite number of times, or indefinitely, affects the strategies individuals adopt. And again, with the same action situation but different individuals participating, we have a different action arena. In other words The number of participants and positions in an action situ tion may vary, but there must be at least two participants in an action situation. Participants need to be able to make choices about the actions they take. The collection of available actions represents the spectrum of possibilities by which participants can produce particular outcomes in that situation.

Information about the situation may vary, but all participants must have access to some common information about the situation otherwise we cannot say that the participants are in the same situation. The costs and benefits assigned to actions and outcomes create incentives for the different possible actions.

When we study an action situation, we analyse the situation as given. We assume the structure of the action situation is fixed for at least the short run. Then we can analyse the action arena by exploring assumptions of the likely human behaviour of the individuals leading to particular outcomes. If action situations do not lead to good outcomes, one may attempt to change the rules. To do so, they must move to action situations at a higher level of decision making such as collective-choice or constitutional-choice action situations, where the outcomes generated are changes in the rules that structure other action situations such as who can participate, what actions are available to them, what payoffs are associated with actions, etc. In a closed society, individuals at an operational level may have little opportunity to change rules at any level and may find themselves in highly exploitative situations.

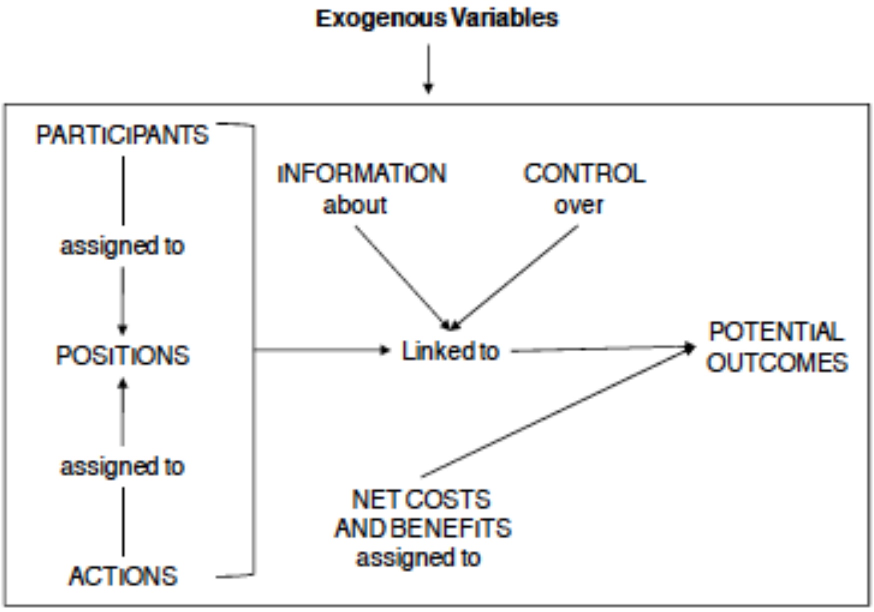

Figure 4 Internal structure of the action situation (Ostrom 2005)

Action situations can be linked through organizational connections (different departments with interlinked activities), can be structured over time (es.sport tournaments) , or they are not formally linked (like the farmer that has better profits because of innovative practice and is then copied by the others).

Another way in which action situations can be linked is through different levels of activities. We can distinguish three levels of rules that cumulatively affect the actions taken and outcomes obtained:

• Operational rules directly affect day-to-day decisions made by the participants in any setting. These can change relatively rapidly—from day to day.

• Collective-choice rules affect operational activities and results through their effects in de- termining who is eligible to be a participant and the specific rules to be used in changing operational rules. These change at a much slower pace.

• Constitutional-choice rules first affect collective-choice activities by determining who is eligible to be a participant and the rules to be used in crafting the set of collective-choice rules that, in turn, affect the set of operational rules. Constitutional-choice rules change at the slowest pace.

An example of an operational-level situation is a group of fishers who decide where and when to fish. At the collective-choice level the group of fishers may decide on which seasons or locations to implement bans on fishing. At the constitutional-choice level decisions are made regarding the conditions required in order to be eligible for membership in the group of fishers. Many social dilemmas can be described from the perspective of an action situation and scholars have used the IAD framework extensively for topic such as urban governance, groundwater, irrigation systems, forestry resources and development policy (Blomquist and deLeon 2011, Bushouse 2011, Heikkila et al. 2011, Oakerson and Parks 2011, Ostrom 2011).

Ostrom's Design Principles

For the purpose to define the attributes that allow an institution to achieve an appropriate and durable role in the sustainable management/governance of common-pool resources, Ostrom (1990) proposed a set of conditions, called "design principles":

- "Clearly defined boundaries: Individuals or households who have right to withdraw resource units from the CPRs must be clearly defined, as must be the boundaries of the CPRs itself."
- "Congruence between (CPRs) appropriation and provision rules and local conditions: Appropriation rules restricting time, place, technology, and/or quantity of resource units must be related to local conditions and to provision rules requiring labour, material, and/or money."
- "Collective-choice arrangements: Most individuals affected by the operational rules can participate in modifying them."
- "Monitoring: Monitors, who actively audit CPRs conditions and Appropriator behaviour, are accountable to the appropriators or are the appropriators."
- "Graduated Sanctions: Appropriators who violate operational rules are likely to be assessed graduated sanctions (depending on the seriousness and the context of the offense) by other appropriators, by officials accountable to these appropriators, or both."
- "Conflict-Resolution Mechanisms: Appropriators and their officials have rapid access to low-cost local arenas to resolve conflicts among appropriators or between appropriators and officials."
- "Minimal recognition of rights to organise: The rights of appropriators to devise their own institutions are not challenged by external governmental authorities."
- "Nested enterprise: Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organised in multiple layers of nested enterprises."

A great deal of researches (Ostrom, 1992; Mosse, 1997; Leach et al., 1999; Blaikie, 2006; Bastakoti and Shivakoti, 2009; Cox et al., 2009, Baggio et al., 2014) tested the above principles reaching different results and evidences. Mosse (1997) and Leach (1999) suggested that these principles are too much abstract when compared to the complexity of the environmental system and to the social domain where actors behave. Blaikie (2006) argued that it could be dangerous to presume the superiority of scientific generality over the empirical context. Cox (Cox et al., 2009) showed that in the most of the cases the principles are consistent with the original intended scope. A similar conclusion is reached by Baggio (2014) that stressed the helpfulness of the approach in identifying important patterns across a range of situations, and in offering an interpretation key of the complexity of the socio-economic-environmental systems. In particular, the Author pointed out that the principles should be analysed as a whole, and that their importance and cognitive contribution depend on the qualities of the investigated resource. In consideration both of the huge scientific interest for the approach and of its coherence with the purposes of the study, Ostrom's principles have been adopted to analyse and evaluate the Lebanese local institutions (WUAs) robustness as defined above.

A framework for the analysis of governance of Social-Ecological Systems (SESs)

In the context of SESs the institutional arrangements pose a big challenge in terms of SES's governance. Ostrom (2009) argues that it is of paramount importance to learn how dissect and harness complexity rather then getting rid of it from such a system. The SES framework emerged from a long process (Anderies et al 2004, Janssen et al 2007), on the basis of IAD, in the attempt to provide scientific community, interested in the sustainability of SES, with a taxonomy that could span across disciplines as a common logic linguistic structure. As a mode of analysis to coherently investigate complex, nested systems operating at multiple scales. Ideally the framework helps scholars and policy makers to seek evidences of the influence of multiple type of governance on resource users and how this affects resource systems. This language –framework is intended to remain theory-neutral, to allow competing hypothesis from alternative theoretical perspective to emerge. As for IAD the SES framework is intended to provide information that can be analysed using several theories and methods.

As we already pointed out, fundamental to SES framework is the assumption that humans can make conscious choices as individuals or as a member of collaborative groups and that this individual or collective choices can potentially make a difference in the outcomes. Originally therefore the SES framework was very close to IAD framework, just Ostrom interest started to shift toward broader set of ecological and social variable for the analysis of SES and the original design was developed for application to a relatively well defined domain of common-pool resource management situations in which resource users extract resource units from a resource system. The resource users also provide for the maintenance of the resource system according to rules and procedures determined by an overarching governance system and in the context of related ecological systems and broader socio political- economic settings. The processes of extraction and maintenance were identified as among the most important forms of interactions and outcomes that were located in the very centre of this framework and that correspond to the action situation of IAD Figura 4.

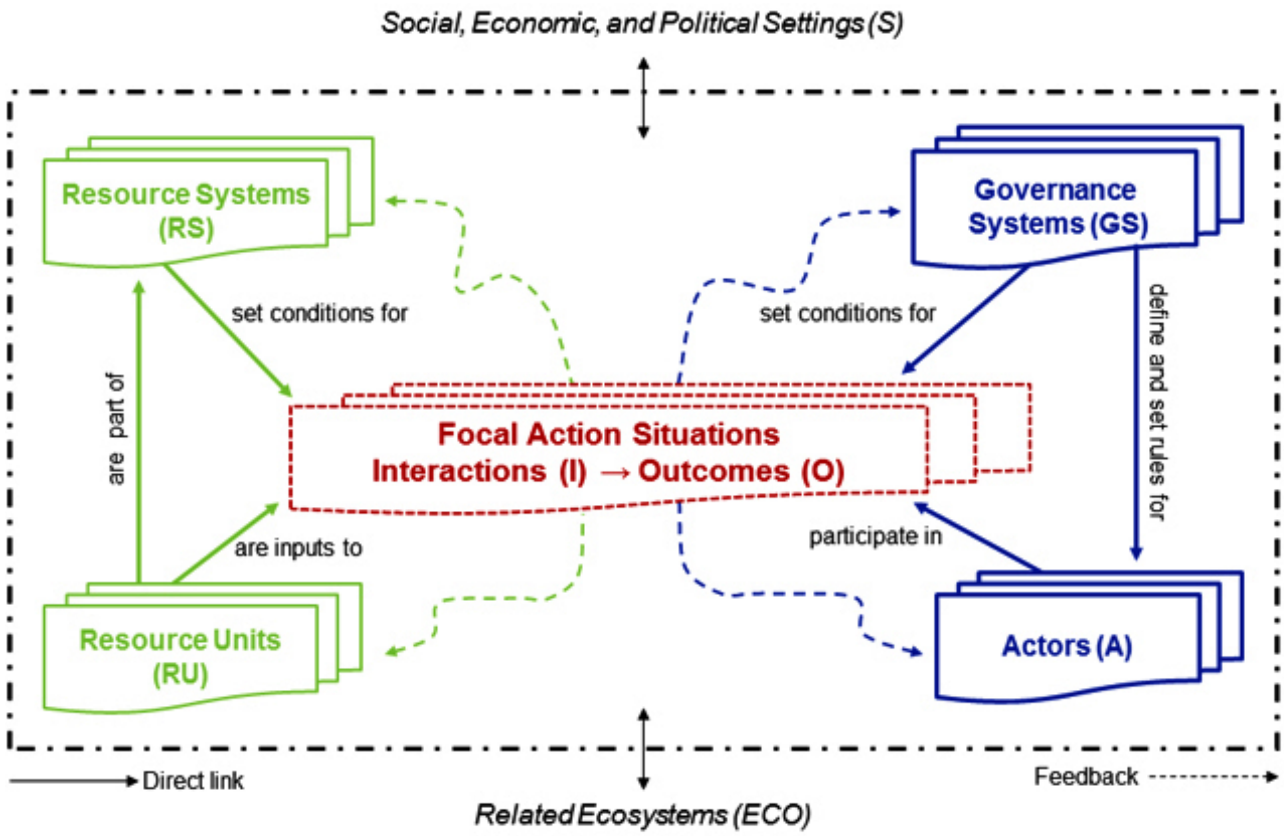

Figure 5 Sioco Ecologial system Famework, Source McGinnis and Ostrom, 2011

The core action situation is connected with tiers that belong to different logical categories. Solid boxes denote first-tier categories. Resource Systems, Resource Units, Governance Systems, and Actors are the highest-tier variables that contain multiple variables at the second tier as well as lower tiers (see Table 1) for an updated list of second-tier variables within each of the top-tier categories). Action Situations are where all the action takes place as inputs are transformed by the actions of multiple actors into outcomes. Dashed arrows denote feedback from action situations to each of the top-tier categories. The dotted-and-dashed line that surrounds the interior elements of the figure indicates that the focal SES can be considered as a logical whole, but that exogenous influences from related ecological systems or social-economic-political settings can affect any component of the SES. These exogenous influences might emerge from the dynamic operation of processes at larger or smaller scales than that of the focal SES.

Both IAD and SES framework have action situations and feedback paths linking outcomes of action situation to the contextual variables. SES framework has a fuller elaboration of the relevant contextual factors that contribute to a definition of the situation confronting actors located with in SES. The patterns of behaviours actors exhibit can then be characterized with reference to the second-tier and lower –tier variables included in SES Action Situation Categories. Furthermore factors listed in the SES framework are best interpreted as state variables in a place at a give point in time. Outcomes of any process in the action situation might influence the value of the system at later times. In SES the

direct participants are called "Actors" to include third parties and their behaviours which are not user or consumer.
Application of this framework resembles the IAD framework but has the advantage to see the system from a general perspective and permits to focus on certain subsystems and variables.

First-tier variable	Second-tier variables
Social, economic, and political settings (S)	S1 – Economic development
	S2 – Demographic trends
	S3 – Political stability
	S4 – Other governance systems
	S5 – Markets
	S6 – Media organizations
	S7 – Technology
Resource systems (RS)	RS1 – Sector (e.g., water, forests, pasture, fish)
	RS2 – Clarity of system boundaries
	RS3 – Size of resource system
	RS4 – Human-constructed facilities
	RS5 – Productivity of system
	RS6 – Equilibrium properties
	RS7 – Predictability of system dynamics
	RS8 – Storage characteristics
	RS9 – Location
Governance systems (GS)	GS1 – Government organizations
	GS2 – Nongovernment organizations
	GS3 – Network structure
	GS4 – Property-rights systems
	GS5 – Operational-choice rules
	GS6 – Collective-choice rules
	GS7 – Constitutional-choice rules
	GS8 – Monitoring and sanctioning rules
Resource units (RU)	RU1 – Resource unit mobility
	RU2 – Growth or replacement rate
	RU3 – Interaction among resource units
	RU4 – Economic value
	RU5 – Number of units
	RU6 – Distinctive characteristics
	RU7 – Spatial and temporal distribution
Actors (A)	A1 – Number of relevant actors
	A2 – Socioeconomic attributes
	A3 – History or past experiences
	A4 – Location
	A5 – Leadership/entrepreneurship
	A6 – Norms (trust-reciprocity)/social capital
	A7 – Knowledge of SES/mental models
	A8 – Importance of resource (dependence)
	A9 – Technologies available
Action situations: Interactions (I) → Outcomes (O)	I1 – Harvesting
	I2 – Information sharing
	I3 – Deliberation processes
	I4 – Conflicts
	I5 – Investment activities
	I6 – Lobbying activities
	I7 – Self-organizing activities
	I8 – Networking activities
	I9 – Monitoring activities
	I10 – Evaluative activities
	O1 – Social performance measures (e.g., efficiency, equity, accountability, sustainability)
	O2 – Ecological performance measures (e.g., overharvested, resilience, biodiversity, sustainability)
	O3 – Externalities to other SESs
Related ecosystems (ECO)	ECO1 – Climate patterns
	ECO2 – Pollution patterns
	ECO3 – Flows into and out of focal SES

Table 1 second tier variables (ostrom 2009; 421)

Theoretical models to address significant variables

The finding of IAD and SES framework can be easily used for simple reality representations, to feed theoretical models like in game theory as well as to nourish artificial intelligent models representing reality for scenario simulations. In fact they offer both a taxonomy and an ontology with categories under which they provide schematic representation of reality, of the different factors insisting on a given context and of their interaction in a given time and space.

Several pre-condition allowed scientist to turn into this direction. Firstly both theoretical than computational models are able to accommodate complex systems characteristics. Models can mimic the context specific interaction and social dilemmas occurring at multiple spatial and temporal scales, using factors and features of the agents and systems involved. Models can also be very close to reality or they can simply use few of the information collected and in this case difference lies in the capacity to generalize and abstract the findings with an inductive approach for broader generalization. Secondly these models can also include uncertainty as it is now perceived unavoidable and permanent, so a fundamental element to study SESs transformation and adaptability, rather than a situation to "get rid of" (Brugnach et al 2008). In this research the theoretical models have been developed a) to address the social dilemma in a manner that goes beyond a specific case and b) to obtain relevant theoretical explanation (emergence of behaviours) focusing on significant variables (water uncertainty) without losing sight of the reference framework.

However when modelling SES, the intrinsic complexity to be described requires to integrate both social and natural science methods as the centrality of human-decision making, for policy development using computer-generated agents in SES simulations, makes it critical to employ models that closely approximate real human-decision making behaviour. In the following paragraph recent findings that underpins the present study are presented.

Coupled social and environmental systems have been recently modelled using more integration between economic and ecological models (Schlüter et al. 2011). Recently Schluter et al (2017) introduced a new framework for modelling human behaviours called "MoHub" or Modelling Human Behaviour and applied it to a number of well-established social-science theories. The framework provide a mapping to describe, organize and compare different behavioural theories and argue that the main challenge for building model and accounting for human behaviours is that theories in the social science are scattered across disciplines (psychology, economics, anthropology, sociology, political science etc…), they use different terminologies and some are generic while other are more specific. This created a gap between human –behaviour modelling and the variety of nuances of human-decision making in the real world. Therefore I'm aware of the difficulties in modelling human behaviours and made a choice of simplicity to introduce a simple learning routine and a reciprocity mechanism to model human-decision making. Further to this, recent findings to study human-decision makers and the way they make strategic decision, underline the relevant role of information and knowledge available. Therefore a new branch of natural resource and management science is incorporating information (Polasky et al, 2011), cognitive process (Beratan, 2007), social learning (Pahl-Wostl, 2008) and behaviours (Li An & Lopez-Carr, 2012) into models to explore human decision-making and cooperative behaviours under uncertainty.

Game theory to model agents' behaviours

Game theoretic principles have been largely used to gain understanding of decision-making when players interact. Game Theory (GT) is an analytical tool that uses mathematics to formally represent, in a highly abstract way, real life situations of competition and coordination. Under a game theoretic approach the outcome of a situation (game), that might not been intended by any player, is the result of the moves (strategy) made by participants (players) in the game. Therefore each game consists of a set of players, a set of strategies available to them and the specification of players' payoffs for each combination of such strategies (possible outcomes of the game). The aim of each player is to maximize its payoff taking into consideration the other player's strategy.

GT gained attention because it enables the simulation of self-interested player in a fairly realistic manner if compared to other conventional methods of strategic analysis, such as linear programming. In addition GT provides better understanding on competition and cooperation phenomena between players, on the outcomes of these interaction and enables to reflect on possible solutions. GT has been largely adopted in economics since its introduction by von Neumann and Morgenstern (1944), but it found application in a number of other fields like political science, biology, psychology, computer science and also in the natural resource management field. In particular water resource analysis has introduced game theory as a framework to study water conflicts (Carraro et al. 2005; Parrachino et al. 2006), groundwater management (Loaiciga, 2004), water allocation strategies (Dinar and Farolfi, 2006) and other types of water resource management problems (see Madani, 2010, for a review). Conflicts over irrigation water have also been studied through the lens of game theory: Galaz (2004) demonstrated how water markets should take into consideration water rights of unprivileged users, Madani (2010) proposed a dynamic game to explore the maintenance of an irrigation system over time. Nevertheless conflicts over water resources in agriculture have a long history and many researchers trying to develop practical and sustainable solutions entered the debate using game theoretical approaches (see Podimata & Yannopoulos, 2014, for a review).

There are two main branches of GT: non-cooperative and cooperative game theory. The former refers to a game in which *individual* players interact with others trying to achieve their own goals without any agreement or coalition and they act competitively. The latter analyses games in which *groups* of players are driven into mutually binding agreements. For the scope of our research we refer to individual farmers, as we are interested in individual decision-making, and for this reason we chose a non-cooperative game under condition of non binding agreements. There are also other types of classification for the

games like games with complete (perfect) or incomplete (imperfect) information, in which the payoff can be known or not by the other player. In our game players do not know the other player' results as it could be the case in most real life situations.
In addition there are a large variety of games that define GT concepts and that are used to represent social dilemmas and CPR situations: Prisoner Dilemma Game, Stag-Hunt game, Chicken game, The Battle of Sexes etc. In the literature the most explored type of social dilemma, as metaphor for collective action problems, is the Prisoner Dilemma (PD) game, but other types of game models well represent CPR situations, as PD embed certain limitation: it does not provide insight of how or why collective actions starts and are maintained, focusing more on how social institution tent to collapse (Runge, 1984); it mainly describes open access CPR problems where stakeholders are totally coerced to act independently (Ostrom, 1990), while this is rarely the case in real world. Moreover in PD game players face a conflict between mutual and individual benefit, since a player "benefit more by exploiting the others' desire to cooperate that to cooperate themselves" (Nokleby and Stirling, 2006). On the contrary coordination game like the Stag-Hunt (SH), better represent a situation of human interaction, in which cooperation maximize both mutual and individual benefit and the individuals' choice depends on the expectations on what the other player will do (Skyrms, 2001). In fact in SH there are two pure strategies Nash Equilibriums (NE) representing the solution concepts of the game. One is considered "payoff dominant", and in this equilibrium both players cooperate, and they are better off in terms of payoff, but they take the risk of failure if the other player fails to cooperate. The other NE is considered "risk dominant" and both players defect acting individually, if it has the largest basin of attraction (i.e is less risky). This implies that the more uncertainty players have about the action of the other player(s), the more likely they will chose the strategy corresponding. In addition defecting alone is preferred to defecting with others and being in competition. The SH was originally described by Rousseau in its *Discourse on Inequality* and as it is usually formalized, it involves two hunters. They can catch a stag only if they cooperate, but each can hunt a hare by acting alone and non-cooperating. Therefore the possible actions of this game are defined as follows: both players may hunt a stag, one of the player may hunt a stag while the other hunt a hare or they may both hunt a hare. Traditionally this game is used to model systems where agents can benefit by cooperation, but this choice entails the risk of failure. For the scope of the research, game theory has been applied to study the Lebanese WUAs and their future developments facing water-changing conditions. Progressing on the work carried out GT, in particular SH, has been used in the elaboration of the theoretical model. The two strategies have been designed to explore uncertainty and its effect on players' choice. In this game the payoff dominant strategy reflects mutual benefit in terms of payoff for the players involved. In addition it embed ecological system gains in terms of lower level of water consumption necessary to achieve a full yield. On the other hand the risk in this strategy is not only in the possible defection of the players but also in the crop used in the model which is sensitive to water scarcity, as it reach it maximum productivity with high level of water availability. Similarly the risk dominant strategy enables farmers to achieve a lower but sure payoff also in function of a more

"robust" crop that can reach a good level of production even with lower level of water availability. With the payoff matrix proposed computed using the theoretical model and a determinate quantity of water the game estimate that (defect –defect) risk dominate the strategy (coordinate-coordinate) with a basin of attraction equal to 0.83 (Goldman and Page, 2009). This help predicting that players will prefer to defect rather than cooperate, questions to be explored is if other factors can alter this result and if any personal attitude can also deviate from predicted results. Further investigation has been then realized with the support of agent-based models, as this approach results easier to use and more flexible and adaptable to research scope.

Agent Based Modelling to represent Socio-Ecological Systems

Decrease in exploitable water resources and climate change uncertainty under a growing population pressure, have increased competition of farmers over the available resources. The complexity of this type of SES and the challenges they have to face of repentine changes in the available water resources and of conflicting interests requires researcher to adopt new approaches. Here we propose to combine game theoretic principle to agent based modelling. The agent-based approach will enable us to expand traditional game theoretical simulation, going beyond bounded rationality, and dig deeper in the complexity of SES, focusing on the impacts of water uncertainty over time in defined circumstances, in our case how water variability impacts farmers' decision-making. Agent-based models (ABMs) have become widely used to analyse complex systems dynamics and to depict how system's level properties emerge from the adaptive agents' behaviours as well as how the system affects agents, since they allow representing complex system and the interaction among dynamic and autonomous entities (Janssen 2002, Bousquet and LePage 2004, Barreteau et al. 2004, Janssen and Ostrom 2006). In particular, ABMs have been successfully applied in the study of irrigation systems (Barreteau & Bousquet, 2000; Schlüter et al, 2007; Balbi er al, 2012) because they allow exploring changes in the behaviour of individual actors that arise from perceived changes in their natural or social environment. However GT provides a useful framework to interpret the results of ABMs and analyse both agents' behaviours and emergent patterns. To this extent, GT has been applied in a number of ABM cases like to study information sharing in organization (Jolly and Wakeland, 2008), to explain a dynamic market change in the California electricity crises (Sueyoshi, 2009) as theoretical framework to design agent's strategy choices in multi-agent systems (Pendharkar 2012). However this approach has not been used to investigate impacts of water variability on strategic decision-making in irrigation SES, while prediction and interpretation thus achieved could be a starting point to design effective policy solutions to address the adaptation of irrigation self-governing institutions to environmental variability. Furthermore Edmonds (2014) advocates for the necessity to include context dependent human abilities such as memory and learning into ABM in order to computational devices to better analyse societies. Therefore taking into consideration the research question, the knowledge gap to be addressed and the indication expressed by Edmonds, our approach has taken the direction to explore how decision-making is affected by environmental uncertainty and context- dependent learning capabilities. Agent Based Modelling is the appropriate tool in this research to go beyond game theoretical prediction, including knowledge and water variability as factors influencing human strategic decision-making. Furthermore, ABM techniques allow building up models with a modular approach. The initial model can be easily expanded as the research progress.

4 Modelling: robustness of Lebanese water users associations

Lebanon an overview of the present situation

Water scarcity has been emerging as a significant problem in arid and semi-arid regions, like in the Middle East and North Africa (MENA) region taken into exam by the study. With reference to this area, literature shows that misallocation and mismanagement have largely contributed to cause the current water stress and to weaken the capacity to tackle the foreseen water shortage (Bou-Zeid and El-Fadel, 2002; El-Fadel et al., 2012). A broader consensus states in fact that climate change will be noteworthy in the region with a deriving increase of dry days (Sowers et al., 2010; IPCC, 2014). Nevertheless, due to the spatial and temporal uncertainty that characterizes the expected climate impacts, local public authorities usually tend to respond to water scarcity by relying upon supply-oriented solutions (e.g. infrastructures), rather than to address water governance and management issues.

In addition, according to recent studies on water deficit in Lebanon, population growth and economic development are expected to put additional pressure on scarce surface water resources in a context where current levels of consumption are already not sustainable (El-Fadel et al., 2000; MoE/UNDP/ECODIT, 2011). Household and industrial water demand is in fact competing with the primary sector requirements - driven by the expansion of irrigated agricultural land - that amount to the 60% of the water use in Lebanon (FAO, 2014). Given the fragility of the system, any alteration in climatic patterns leading to increase of temperature and reduction of rainfall would greatly exacerbate existing difficulties, especially for the irrigation activities (Bou-Zeid and El-Fadel, 2002). In order to respond to future water shortage, the Lebanese government has launched a ten-year infrastructural plan based on the realization of dams, artificial ponds, and irrigation channels (NPMPLT, 2005). Besides public intervention, researches focused on water use in agriculture in Lebanon (Gharios, 2009; El Chami and Karaa, 2012; Lamaddalena and Khadra, 2012) advocate that farsighted governance initiatives should be taken to foster direct and responsible participation of farmers in designing, implementing and managing irrigation programs. For this purpose, it appears that local institutions (the Lebanese Water Users Associations, WUAs) can play a strategic role. In fact, not only WUAs are widespread in the country's rural areas, but also they have been demonstrating that proper governance schemes can ensure efficient and sustainable water management (Gharios, 2009; Lamaddalena and Khadra, 2012). Nevertheless it must be highlighted that the need to analyse functioning and potentiality of these Lebanese institutions is unfulfilled and, in particular, that rules they adopt to regulate members' decisions dealing with water scarcity are, to a great extent, still unexplored.

Water governance and institutions in Lebanon

Lebanon was deeply signed by several decades of conflicts and all efforts are now directed to restore stability and wellbeing. Eventually, the effects of these conflicts are still perceived today. It suffices here to highlight some points relevant to irrigation systems management. Lebanon receives an abundant rainfall of 800 mm/year as compared to 252 mm/year in Syria and 111 mm/year in Jordan (Comair, 2007; MoE/UNDP/ECODIT, 2011). Nevertheless a growing demand of fresh water for irrigation, household and industrial use is already triggering water deficit estimated at 388 Mm3 during the summer months. In addition, average temperatures are expected to increase from around 1°C on the coast to 2°C in the mainland by 2040, and 3.5°C to 5°C by 2090, while projections on rainfall depict a decrease of 10-20% by 2040, and of 25-45% by 2090 (MoE/UNDP/ECODIT, 2011). The combinatory effect of these phenomena will cause an extended water shortage. In order to face it, the Lebanese government launched in 1999 a ten-year water master plan of investments and, in 2000, an institutional reform to regulate the water use in the different sectors. Up to recent years, both the measures resulted to be unfulfilled: in particular, the foreseen institutions have not replaced the old ones, while traditional customs and habits that regulate water allocation are still in force (Comair, 2007).

The importance of water governance has long being recognized in Lebanon for the purpose to spread efficient water management solutions, and to avoid conflicts. The Majallah code (1839) first codified customs, habits and concessions. Afterward, water resources were declared public properties and water rights established. Some specific limitations were introduced in case of private ownership and acquired rights on water resources (heritage, donation, and purchase done before 1926, due to the Majallah code that permitted the acquisition of good with no owner, such was water). Furthermore in 1930 the Government of Lebanon issued a decree, which considered that water in a private land is property of the owner. Since then, several attempts to reorganize the water system were made but, due to long periods of instability, the reform was never accomplished. More recently (2000), a national normative delineated a new institutional framework for water governance in Lebanon (Comair, 2007) composed of:

- Ministry of Energy and Water (MoEW) in charge of the definition of the national water policy, of the national master plan as well as of the execution of hydraulic projects;
- Ministry of Agriculture (MoA) the role of which is focused on the monitoring of irrigation water quality, and on the coordination of the research, extension services, and farmers training;
- Water Establishments (WEs), regional entities operating (in Beirut-Mount Lebanon, North, South and Bekaa) under the control of the MoEW, and responsible for potable and irrigation water consumption, waste water issues, financial investments, projects design, operation and maintenance, and tariff collection from water users. Currently, some WEs functions (and, in particular, the management of networks and equipment) are carried out by former institutions, namely the Local Committee and Irrigation Committee;

- Litani River Authority (LRA), a body deputed to the design and financing of water related projects in the Litani River Basin (e.g. domestic, irrigation, and hydropower water schemes), whereas the South-WE is the responsible for the local potable and waste water management issues.

Despite the assignment of roles and responsibilities, functions and initiatives of the above institutions often result to be not clearly integrated, and not enough effective to ensure a suitable water governance.

Lebanese Local Water Institutions

Lebanese Farmers' communities have long-lasting tradition of water use agreements as well as of irrigation system management, although the only existing national law establishing WUAs, that dates back to the French mandate (1926), has never been applied due to its complex framework. Recently, the MoEW in its National Water Sector Strategy (2012) has explicitly assigned a role to WUAs for the operation and maintenance (O&M) of secondary and tertiary irrigation schemes, and for collecting water fees, but until now no official legislation is in place. Therefore, farmers wishing to organize irrigation systems on collaborative bases currently prefer to constitute agricultural cooperatives, as foreseen by the MoA. Cooperatives must adopt a statute defining operational rules and the management structure, namely a general assembly of all the members that elects a Board of Directors. It derives a not clear definition and assignment of roles and responsibilities among central institutions and local organizations (WUAs and cooperatives) that generates overlapped competences in water management issues. The delay of the water reform has not yet permitted to settle this dispute. Furthermore, according to data only the 3% of Lebanese farmers declared to belong to any collective organisation (MoA, FAO, Cooperazione Italiana allo Sviluppo, 2012). A quota that undoubtedly shows the weakness of local institutions in the Lebanese agricultural panorama, and that highlights the organizational limits that hind participative and collaborative ways to use water resources for irrigation. As a consequence, ready to use information and analysis aimed at supporting the political development of crafting well-functioning local institutions can assume a strategic relevance in a context of increasing water scarcity.

Robustness of Lebanese local institutions

Lebanese participative institutions (WUAs) operate locally to manage the available water resources, in response to the lack of maintenance of infrastructures and to the proliferation of illegal wells that provoke an uncontrolled water overuse and increasing allocative inequalities. All the five local institutions described here below (the Agricultural Cooperative Association of Mchaytiyyeh, the Lake Share Communities Union in South Bekaa, the Irrigation Water Users Association of Jabboule, the Marjeyoun-Khiam Plain Water Users Association, the Btedhi Water Users Cooperative) have legal status and their institutional organizations represent the formerly defined WUA. Next paragraphs are based on data and information collected from Gharios (2009) and Lamaddalena and Khadra (2012).

"Agricultural Cooperative Association of Mchaytiyyeh"

a) Community attributes: karstic geological features characterise the small valley of Mchaytiyyeh, where water has always been scarce. Thus farmers were only growing rainfed crops, mainly cereals, or digging their own wells that soon became too expensive due to the deepness of the aquifer. With the help of donors, it was possible to dig a well 8 km uphill from the village, where water was available from a direct source. To store the extracted water farmers built a reservoir of 25,000 m3 of capacity at 1 km ascending from the village. In order to deliver the water to the plots around the village, farmers constructed two pressurised main canals. As a consequence, farmers were soon able to irrigate their plots, to switch to more productive crops, like apple, and to reclaim other land to cultivate from the mountains. The driving force establishing this WUA was a Lebanese official willing to help the villages, yet farmers - tied together by family links - demonstrated to understand the power of collective action in regulating the utilisation of water through the newly built canals.

b) Institutional settings: in Mchaytiyyeh there are internal laws establishing an administrative council as well as a surveillance committee elected every two-year. A caretaker has been appointed to check the compliance with irrigation scheduling and distribution of water. Any offender can be first warned and then inflicted for crime. Communication is done using both letters and mobile phone messages. Farmers pay a fee to the association for each drip point and proportional to the production. In return, the WUA provides additional services such as: common tractor, cooperative fridge, fertilisers and marketing services.

"Lake Share Communities Union in South Bekaa"

a) Community attributes: main scope of the community of South Bekaa is to efficiently exploit the water under the South Bekaa Irrigation Scheme (Canal 900) as a part of the national irrigation scheme plan of the Litani River Authority (LRA). Canal 900 consists of 18 km underground-pressurised canals that distribute water over a total area of 2,000 ha. The LRA is in charge of Canal 900 management and the Lake Share Community has been created for Canal 900 O&M. Initially, not all farmers of the area took part in the community and non-members received water from the scheme regardless of their participation to the association. Thus a sense of uselessness to participate to the WUA spread and many farmers initiated to flout the norms, to eliminate flow regulators, and to misuse the hydrants. As a consequence, many tail-enders farmers were not able to receive water, although members of the WUA. An awareness raising campaign with the support of the local municipality helped to recover the situation and 40 farmers are currently members of the WUA. Yet the local community is heterogeneous and there are not ties, like family ones, keeping them together. Furthermore farmers are poorly educated. All these factors are considered to be behind the low success rate of the Lake share Communities Union.

b) Institutional settings: the cooperative has internal laws establishing an administrative council elected every two years. Conflicts are resolved outside the WUA with the involvement of the Municipality and LRA.

"Irrigation Water Users Association of Jabboule"

a) Community attributes: the irrigation community was created by international donors to address rural development in the semi-arid climatic area of Jabbouleh (less than 400 mm/year of rain), where agricultural activities showed inadequate yields. With the specific objective to optimise the existing water resources, the system built in Jabboule includes a hill lake of 20,000 m3 in connection with a collective pressurised irrigation network covering 100 ha, and five reservoirs of 2,000 m3 each feeding an area of about 20 ha. The capacity of each reservoir corresponds to the sum of farmers' water rights connected to the pool. To effectively manage the distribution of the resource, an electronic system (the so-called AquaCard®) was introduced, together with a mechanisation process. The local community can be considered quite homogeneous since all farmers rent the lands from the same owner (the Catholic Diocese).

b) Institutional settings: in Jabbouleh, farmers gather together to elaborate the seasonal irrigation schedule and since the systems effectively allow controlling water level, they also assemble to agree on the amount of water allocated to each individual prior to start the irrigation period. The above mentioned electronic card is working as a controller since it is not allowed to take more water than the one formerly agreed and paid for, while conflicts have been sensibly reduced.

"Marjeyoun-Khiam Plain Water Users Association"

a) Community attributes: in a post-conflict operation in Marjeyoun-Khiam area, international cooperation set up a plan for the invigoration of the local rural economy. The land is a fertile plain, very rich in water springs of which the Dirdara natural pool is considered the main source of water for irrigation. Previous to Israeli occupation, concrete canals where feeding the cultivated land with a caretaker responsible for the equitable distribution of water. When Israeli troops left, after 22 years, the system was unusable and land unfarmed. Farmers were using unlicensed wells and some put pumps directly into the pool. The intervention of international cooperation in the area restored the Dirdara irrigation network, replacing old canals with underground pipelines with flow meters measuring the quantity of water distributed in the territory. The WUA was thus created to manage the new built system and monitor compliance with the rules adopted. Rapidly farmers were able to shift to more profitable crops like stone fruits and water was available even to the tail-enders.

b) Institutional settings: in Marjeyoun a caretaker is responsible for the scheduling and distribution of water and farmers participate in the management of the association. The strong political support and the enforcement in place to forbid private wells facilitated the switch to the irrigation scheme.

Btedhi Water Users Cooperative

a) Community attributes: in Btedhi district, agriculture is the main economic activity. Long and severe periods of draught were increasing desertification phenomena in the area and farmers incapable to regain fertile land started to flee the district. Water was potentially available, in excess during winter and spring seasons, but the community was not able to store it for the dry period. For this reason the international donors' intervention concentrated on two main actions: an infrastructure intervention with the construction of a 85,000 m3 reservoir and the installation of a tertiary pressurised distribution network, and the set up of an association to collectively manage and operate the system.

b) Institutional settings: in Btedhi, all villagers are eligible for membership (residents or non-residents) and all the shareholders have the same weight and voting power, regardless of the shares they own. Members elect the Management Board and the Foresight Committee, they pay a cost for water use, and they are responsible for network protection and to establish and comply with the irrigation calendar. The Board is responsible, among other duties, to solve conflicts. In this community there is an enforcement system for those members not fulfilling their obligation. The WUA is in general responsible for O&M and fees collection. These fees are devoted to pay the Government for the water supplied and the caretaker and are accounted for unforeseen emergency.

Outcomes and feedbacks of WUAs

The five areas analysed above suffered in the past from water scarcity as a consequence of unsatisfactory resource governance and management as well as of lack of infrastructures causing a widespread abandonment of the lands. The institution of the WUAs contributed significantly to change the situation: they made water available to all the farmers, permitted the return of those producers that fled during the war, and allowed more profitable crop production activities. Farmers were able to reclaim additional land as greater efficiency was achieved thanks to the introduction of modern irrigation techniques like drip and sprinkler systems. Although water scarcity problems still remain in South Bekaa, in the considered regions agriculture is currently a remunerative activity and farmers are committed to further increase the management capacity of the WUA as a strategic issue for the competitiveness of their businesses and for the sustainable use of the water resources.

Lebanese WUAs for the most part result to be fragile bodies, essentially because they lack institutional recognition from Lebanese administration at National, Regional or Local level. Mainly for this reason, they do not participate (or, if they do, they are powerless) to the processes of definition of public choices and of development of collective rules required for an efficient and equitable governance and management of the water resource.

Design principle 1. Clearly defined boundaries: the majority of Lebanese WUAs have quite clear boundaries with the exception of South Bekaa where not all farmers are members of the association. In South Bekaa non-members get water, but many of them, during their turn of irrigation, overuse the resource beyond the amount needed and eventually agreed. This behaviour leaves other farmers and WUA members without their share of water. Thus farmers realise that their membership is useless, generating the problem described above in section (2.2.2). Limits to the use of water are an essential condition to successfully set up a WUA that, on contrary, should be exposed to failure.

Design principle 2. Congruence between appropriation and provision rules and local conditions: in most of the cases taken into exam, WUAs provide services to their associates as a reward for the payment of operational fees. Rules vary from case to case. In particular, in Mchaytyyeh farmers share maintenance costs and reward WUA with a fee proportionated to the number of drip points and to the yearly yield. In return, they receive some supplementary free services: a caretaker responsible for monitoring and controlling water distribution and the respect of allocation agreements (in Marjeyoun too), a tractor to be used collectively, a fridge to store the fruit to be sold, the assistance and the marketing advices. Differently, in South Bekaa WUA is not able to provide additional services to its members and farmers' feel their membership useless. This element further contributes to make this WUA prone to failure.

Design principle 3. Collective-choice arrangements: currently Lebanese WUAs do not have legal basis given the lack of a specific normative. Furthermore, they are not at all, and under any circumstance, involved in joint decisional processes. Even though MoEW made an explicit plan to involve WUAs in the governance and management of water resources at the secondary and tertiary level, and the Integrated Water Resource Management approach, introduced in the country, clearly assigned a role to this form of organisations, Lebanese WUAs and their farmers do not participate in collective–choice arrangements. To this extent, Ostrom (1992) argues that this principle is strongly correlated with successful governance and management of common pool resources especially when dealing with varying environmental conditions. The disregard of this condition makes all the Lebanese WUAs fragile organizations since the farmers are not in the position, for example, to tailor rules in accordance with local circumstances.

Design principle 4. Monitoring: in Lebanese WUAs a professional, hired by the association or by the farmers, normally performs monitoring activities. To this regard, Jabbouleh is an exception. In the irrigated land where the AquaCard® system has been adopted (2.2.3), there is no possibility for farmers to free ride or cheat. The monitoring is normally a service offered by the local association to its members and it is included in the farmers' fee paid to the WUA.

Design principle 5. Graduated sanction: in the examined cases, violating rules-in-use and sanctioning are very rare. Defectors can receive graduated penalties in accordance to the level of their misconduct (in particular, in Btedhi a reduction of the furnished water is applied to free riders), but the sanctions are normally low. Probably, positive conditions of collaboration, newfound agricultural capacity, and appropriate distribution of water resources are some of the factors favouring the commitment to the rules in place. Only in South Bekaa (2.2.2), where farmers show a weak feeling about their participation to the WUA, episodes of defections occur. Furthermore, again in South Bekaa external actors like the municipality or the LRA are involved in sanctioning the defectors, while Ostrom (1992) suggested that in robust organisations this mechanism should be undertaken by farmers themselves through their association and not outside.

Design principle 6. Conflict resolution mechanism: in the cases in exam, the internal negotiation system is either nested in the management structure of the WUAs or, as in South Bekaa, external actors - like the municipality or the LRA - are involved in conflicts resolution. Once again it can be stated that the observed positive experiences and results in general achieved by the WUAs are most probably reducing the need to activate this mechanism.

Design principle 7. Minimal recognition of rights to organise: no normative measures are currently in place to formally recognize to Lebanese Water Users Associations a role of governance of the irrigation systems. For this reason, the existing WUAs make use of a ploy to act as local institutions by leveraging on their role of agricultural cooperatives under the MoA's regulatory provisions. This situation generates an overlapping of competencies between MoEW and MoA. As a consequence, any future legislative recognition of the WUAs operating in the country should take this condition into consideration as it hampers the development of WUA and the deployment of water governance schemes at secondary and tertiary level.

Design principle 8. Nested enterprise: in Lebanon, farmers and their local organisations are not yet involved in any decisional process at any level, thus this principle is not applicable to the analysed case studies.

	Mchaytiyyeh	South Bekaa	Jabbouleh	Marjeyoun	Btedhi
1. Defined boundaries & membership	Yes	No	Yes	Yes	Yes
2. Congruent rules	Yes	No	Yes	Yes	Yes
3. Collective choice	No	No	No	No	No
4. Monitoring	Yes	NA	Yes	Yes	Yes
5. Graduated sanctions	Yes	NA	NA	Yes	Yes
6. Conflict resolution mechanism	Yes	No	NA	Yes	Yes
7. Recognition of rights	Yes	Yes	Yes	Yes	Yes
8. Nested enterprises	No	No	No	No	No
Institutional performance	**Fragile**	**Failure**	**Fragile**	**Fragile**	**Fragile**

Figure 6 Robustness oaf Lebanese WUAs evaluated against design principles. (Source Tegoni et al, 2016)

4.1 Evolving scenario for Lebanese WUA, a game theoretic approach

WUAs' profile and degree of robustness emerged from the design principles offer the necessary knowledge to develop a dynamic game to study farmers' decision-making strategies and governance rules adaptation when facing water restrictions scenarios.
In this regard the IAD framework has been integrated with a non-cooperative game-theoretic approach to study how changing contexts (uncertainty of water disposal) impact rational players' (producers') decisions, how they interact and behave themselves to adapt their activities (Ostrom et al., 1994), and how institutions can remodel their governance. Game theory offers the opportunity to illustrate how strategic interrelations among players result in overall outcomes that are not necessarily Pareto-optimal and might not have been intended by any player (Nash, 1950). In other words, the self-optimising attitude of stakeholders frequently results in non-cooperative behaviours even when cooperative ones are more beneficial to all parties as a whole.
In order to analyse farmers' decisions and strategies (Madani, 2010; Podimata and Yannopoulos, 2015), and governance solutions (Ansink and Ruijs, 2008) in water use conflict contexts, the game is extended to a dynamic framework in which water conditions are worsening over time. In this scheme, any variation in the resource availability affects users' behaviours. The deriving new outcomes feed back onto participants' choices altering again their results. While in the short run users can simply change their strategy and routine decisions to achieve the desired outcome, in the long run unsatisfactory or unfair outcomes can raise questions and disputes requiring a revision of rules and institutional settings to achieve a more efficient and equitable resource allocation.
With the aim of simulating how water shrinkages (e.g. due to climate change) reverberate on producers' choices, and how these decisions are mutually affected and evolve over time, the study - following Madani (2010) - adopts a dynamic two-by-two water resource game structure. Changing conditions and their impact on agents' outcomes imply the necessity to adapt the rules of the local institution to ensure an appropriate resource use.
Figure n. 2 illustrates a possible evolutionary scheme of the irrigation rules in a participative institution, such as WUAs, when a reduction of water availability occurs. Only two farmers (players), with symmetric production functions and payoffs, are showed; information is assumed to be perfect and two agents' decisions to be simultaneously adopted; sector choice as well as technological and market conditions are supposed to be unchanged. Players can decide if cooperating (i.e. following the WUA rules and limiting the consumption of water to the assigned quota) or defecting (i.e. using higher volumes of water than the allowed ones, in order to get higher payoffs). Payoffs are expressed in cardinal form in order to describe, in qualitative terms and with no specific reference to the case studies, the nature of the interactions between the players. In the following sections, the five Lebanese WUAs have been compared through this general framework fro the purpose to analyse their state, the nature of the existing / possible conflicts, their expected dynamics and to detect feasible solutions.
In particular, it is assumed that, at a starting period 1, a WUA manages a volume of water congruent with the requirements of its associates: users are allowed to reach the planned crop yields and the expected payoffs from their production activities (i.e. 50). In this case,

there is no reason to violate the association's rules, and controls and sanctions are not necessary.

On the contrary, situation can change when shrinkages of water availability in the reference area occur (period 2). In this context, the WUA has to limit the water quotas assigned to each farmer, the payoffs of whom decrease (i.e. 40) due to the deriving production decline. However, farmers can choose to defect new rules in order to consume as much water as necessary to keep the desired yields and payoffs. If producers decide to disregard the association's regulations, too much water will be used for irrigation scopes and the system collapse. In function of specific conditions, different forms of failure can arise: for example, a long-run break down can be due to a durable lowering of the water table level or a short-run one can be confined in a given period as a consequence of a seasonal water overuse. In any of the above cases, game theory suggests that defection is the strictly dominant strategy for both the players, and that a Nash equilibrium can be reached at point (D, D) where each one of them would expect to be better off regardless of what the other player does. This is a classic result of the so-called prisoner's dilemma game structure that describes the situation known as tragedy of the commons (Hardin, 1968): in fact, the players' payoffs is lower (i.e. 20) than what they would get with a cooperation strategy.

In such a circumstance, the local institution (WUA) can introduce (mandatory or governance) measures for enforcing better resolutions in terms of water resource use and farmers' payoffs. If an appropriate financial sanction is applied to defectors (with consequent monitoring), the behaviour of farmers should change. In the example (period 3), a sanction equal to 10 (an amount commensurate with the difference between the starting theoretical payoff and the one achievable through cooperative behaviours) should be sufficient to eliminate any incentive to defection. In this case, cooperation scheme (C, C), the only Pareto-optimal outcome, results to be stable.

In case a further decrease of total water availability happen, the game structure changes again (period 4). Under this new condition, despite of the introduced financial sanction, a farmer would have a higher payoff by adopting a defecting strategy (i.e. 40 vs. 30) if the second farmer still pursues his cooperative strategy. However, differently from the previous prisoner's dilemma structure (period 2), if both players decide to defect, the resulting outcome (due to the cumulative effect caused by the sanction and the water shortage) will be the worst one for the two players. As known, the former structure (defection vs. cooperation) is defined a "chicken game" where two Nash Equilibrium can result, and in which one of the two players wins and the other loses. If the two players have the same characteristics and act under the same conditions as supposed, it will be not possible to define who will defect first, but any possible difference (e.g. crops, technologies, etc.) between the two could explain such a result. Again, the WUA should intervene by reinforcing the sanction (at least 20, in the conjectured case) in order to eliminate incentives for defecting behaviours (period 5).

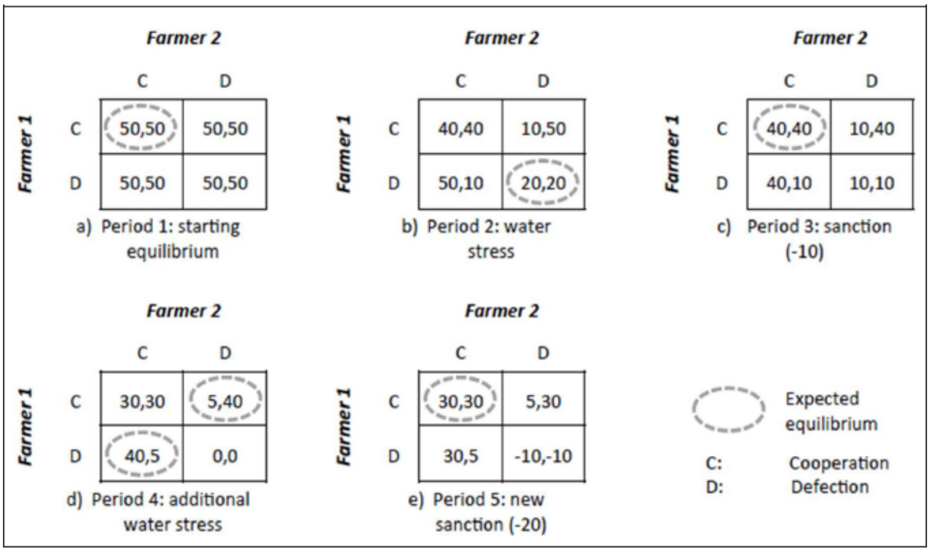

Figure 7 Possible evolutionary schemes of the irrigation rules in a participative institution. (Source Tegoni et al, 2016)

It's in general assumed that the observed farmers' choices are the result of stable technical and economic conditions, consolidated practices and planned production activities from which it derives that the current consumption of water identifies a starting equilibrium among users (figure 7, period 1). This is the situation in which Mchaytyyeh and Marjeyoun appear to be, where resource availability, irrigation network, producers' commitment and institutional setting show a particular congruency (design principle 2), while the only perceived deviation from the state is the farmers' reclamation for additional lands in order to expand their production activity. In Jabbouleh, a technological innovation (the AquaCard® system) has been adopting to monitor the irrigation use of water, and to favour and/or restore cooperation when the resource is scarce (design principle 4.). For this reason, it can be assumed that the mentioned WUA is more likely starting from period 2 "water stress". The phase 3 "sanction" of the game theory scheme seems to identify the initial state for Btedhi, where not cooperating farmers can be sanctioned through a cut of water provisions, and for South Bekaa where both members and not members of the WUA often defect generating water stresses and where an external sanctioning system is then applied (design principle 5.).

In case of a significant drop of total water availability, WUAs initially set in period 1 would move to phase 2 ("water stress"), WUAs already in period 2 would see their situation worsening, whereas WUAs starting at period 3 ("sanction") would shift to period 4 ("more water stress"). Game theory indicates that a reduction in water availability, and the deriving generation of risk for lower incomes, can easily increase the possibility for farmers to adopt free-riding behaviours. In particular, the game structure shows that at period 2 players are at a prisoner dilemma stage: they could be better off cooperating, but for several reasons (mistrust, lack of communication, bargaining costs, etc.) they both defect adopting a dominant strategy and reaching a Nash equilibrium, but not a Pareto-optimal solution.

Those Lebanese WUAs that explicitly foresee the adoption of a graduated sanctioning scheme could apply it at this second stage: the introduction of a fine will reduce non cooperative player's payoff in a way that free riding will no longer be the preferred option. Thus the players could be willing to change their strategy, and the system can evolve to period 3 where non-cooperative behaviour is no longer a dominant strategy. Without an enforcement mechanism, WUAs could most probably suffer an exacerbation of water disputes in the short run, whereas in the long run, if the situation is not restored, they could experience the depletion of the common resource.

In case water quantity is further decreasing, e.g. due to climate change (period 4), the former sanction would not be great enough, and farmer's payoff would be increased if he defects although the penalty to be paid. At this stage, the risk of free riding is higher. Results of the game are changed, and the game evolves in a "chicken game" structure where there are one winner and one loser. In these circumstances, the defection of both players will make the system collapse, and the possible consequences to be borne could be extremely severe. Therefore, an opportune adaptation of the governance system – e.g. adequate increases of the sanction – is required to restore the former cooperative pattern (period 5). In similar situations, experimental studies confirmed that proper levels of disincentive have to be reached in order to promote cooperation and to prevent free-riding behaviours (Ostrom, 1992; Fehr and Gächter, 2000). Nevertheless the punishment can't grow indefinitely and it is necessary to take other factors into consideration.

5 Modelling: possible evolving scenarios of water governance under uncertainty

5.1 Coping with water uncertainty the role of information and behaviours, an agent based model approach

In this section I describe a theoretical model developed to gain better understanding on factors and variable influencing cooperation and decision-making. The model description loosely follows the ODD protocol (Grimm et al, 2006). While a class diagram in UML is proposed to describe the model. Complete UML class sequence and activities diagram are provided in the appendices. The Unified Modelling Language (UML) is used as UML offers a way to describe the features of the model through diverse types of diagrams in a general-purpose recognized modelling language. Thus structural information are presented using class diagrams (describing the static structure of the model: class of entities, attributes, operations and relationships), while dynamic or behavioural view is offered using activity and sequence diagrams, capturing respectively the workflow and how processes operate and interact in a time sequence in the model.

The model *goal* is to analyse the role of information and behaviours on coordination (or not) and the capacity of farmers to cope with alteration of socio-ecological settings.

Entities and their attribute are here described:
To explore social interactions and resource management under uncertainty, the model consists in a simple representation of two symmetric *farmers*, their lands composed of 3 *plots* each, on which they make decision on how to allocate irrigated and rainfed *crops*. A forth entity is a water resource. The water resource is modelled as a pool from which both farmers drawn water for their crops. The *rain* recharges the pool. The last entity is the *market* that computes payoffs.
Farmers are cognitive agents, characterized by the memory of past payoffs updated at the end of each productive season (twice per year); a payoff history that correspond to the farmers' attitude towards the selection of the strategy choice (more or less risk averse), the strategy (S1, S2) representing the set of crop allocation choices, the number of plots they cultivate and irrigate, the water they need to grow their crops, the water they receive from plot, the seasonal yield per crop, the wealth. Farmers interact with the other elements that represent the farmer's environment: Water Pond, Plot, Crop and Market (Fig.1). The latter are reactive entities to farmers' decision making. The Water Pond is the water provision infrastructure system. It is recharged from rainwater. The level of water characterizes the pond. It computes the demand of water from farmers, allocates the available water to the farmers, computes the remaining water and maintains a water level history. Plots are the agricultural area cultivated by farmers, it is composed of three plots of 0,5 Ha of cultivable land each. Each plot can produce only one crop. Plots are characterized also by the water level needed and the water received. The Crop is characterized by type, water need and the price received for the yield produced. In this model three types of crops are available.

C1 that is an industrial irrigated crop, C2 a traditional irrigated crop and C3 a rainfed crop. The Market is computing the crop's price; it buys the available yield and returns the payoff to farmers. Market distinguishes between the traditional crop and the industrial crop. We assume that if all farmers produce traditional crop it will create competition at local level with consequent reduction of its value on the market. This reduction is equal to 25% of its value (figure 9). The industrial crop is purchased by the market only if the amount of crop available satisfy industry request of minimum one Ha. 1 Ha can be achieved by farmers only in case both make the allocation choice to cultivate the industrial crop.

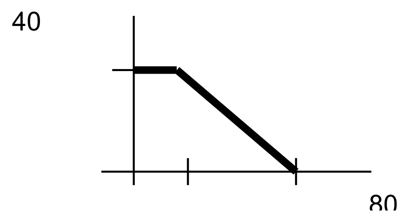

Figure 8 Price for tons of C2

Two different model structures represent the memory, individual and collective. The memory is updated with the results at the end of each productive season for each strategy choice. In the individual version, agents can backward look at 10 payoff values corresponding to 5 years of results. In the collective memory setting both agents individual memory are shared and agents have the possibility to refer to 20 payoff values for 5 years of results.

Famers compare the payoff for each strategy to choose the most profitable crop allocation choice. The selection of the payoff is performed in accordance with their own risk aversion (risk love/seeker, neutral and adverse)

The model does not a include space. Each time step correspond to a season, therefore 2 steps are a year. Simulations are run for 100 steps.

For further detail please refer to the annex 1.

Process overview and scheduling

Each year, a sequence of activities takes place in the following order: At the beginning of each season farmers, that are learning agents, decide a crop allocation on their plots in accordance with both their past experience and their risk aversion. Once the choice is made, the farmers compute the water necessary to reach the full yield of the crops and demand the water to the pond. The pond, considering the water available, provides the available water to the farmers. The plots are then irrigated. At the end of the season the farmers can harvest the yield and sell it to the market that buys the production and return the payoffs to the farmers. To conclude the process the farmers update their payoffs.

For further detail please refer to the annex 2.

Design concepts
Overview:
Emergence: once the boundary conditions of possible water scenario and risk preferences are set for model runs, then the performance of cooperative strategy choice or not is a phenomena that emerges from farmers behaviours. This is numerically expressed in the number of time that farmers chose one strategy or the other and on the strategy choice they coordinate on.

Objectives: The farmers can make a strategic crop allocation choice on their plots. Farmers can chose between an industrial crop or traditional crop, according to their memory of past payoff and based on their risk attitude. The objective function is expressed in form of repetitive attempts under certain conditions. These conditions are represented by several fixed level of water or variable level of water and by individual or collective memory. Famer considered the options and the condition make is crop allocation decision.

Interaction: In this model, that consider both social and ecological uncertainty, farmers make their crops allocation choice simultaneously and unaware of both the other farmer decision and the resource available. A Stag Hunt game is underpinning farmers' interaction. Farmers have a set of possible actions: strategy1 (S1) and strategy2 (S2). Both strategies correspond to a predefined crop allocation choice on their plots. S1 if chosen cooperatively entails social and environmental benefit of higher payoff for a lower level of water necessary to grow the crop, but expose farmers to social risk that the other player will not coordinate and to environmental risk in case of low water availability as the crop is water sensitive. S2 correspond to play safe regardless of the other player decision and environmental uncertainty as this crop is less sensitive to water level. They can only choose one of the two possible actions, in each seasonal period. To select the strategy each farmer compare the payoffs obtained for S1 and S2, stored in a memory of past results for each strategy, giving preference to the most profitable one.

To select a payoff values:

a. In the "individual memory" model, each farmer has a set of 10 results corresponding to 5 years of memory.
b. In the "collective memory" model, farmers share their results, therefore each farmer can count on a set of 20 results over 5 years for each memory.
c. In addition farmers, that are symmetric, are characterized by different risk aversion. This risk aversion is reflected on the in the way they pick up a value in their payoff memory. They can choose results if risk lover/seeker, neutral or adverse. For the scope of the simulation we used the five statistical summary point (Minimum, Maximum, Mean, Median, 1st Quartile, 2nd (last) Quartile) and a random choice possibility to represent this feature.

The memory is initiated with random values and regularly updated with the results of the interaction after the completion of each seasonal time period. These payoffs correspond to the revenues gained by selling the yield available. The seasonal yield is direct consequence of choosing strategy 1 or strategy 2 in relation to the other farmer choice and the water available.

The Stag-Hunt Game*:* Game theory is a "formal mathematical" language that allows us to analyse a situation and determine the preference of the player compared to the results. Decision makers or players, in the classical theory, are considered intelligent and rational. They have complete knowledge and are able to make logical arguments of high complexity such that they can make the best choice to maximize their benefits. The Stag-Hunt is a game of co-ordination, with two Nash equilibrium. One called payoff dominant strategy (coordination and social cooperation) and the other said risk dominant strategy (defection and prevalence of self). In addition defecting alone is preferred to defecting in competition with others. This game lends itself to the investigation of collective action failures/success in socio-ecological systems as the outcome of the interaction are motivated by self/ mutual interest in a group of individuals.
For the scope of the research, our SH game encompass both social that environmental gains/risks. To this extent the "payoff dominant" strategy, if chosen cooperatively, ensures the highest payoff to the players and allows a lower use of the common-pool resource. Yet the player choosing this strategy, is confronted with a dual risk leading to failure: the defection of the other player and the risk of reduced production, as this choice is associated with a water sensitive crop. While the "risk dominant" strategy ensures the player to get a lower but sure payoff, regardless of what the other player does. In case both players select this strategy, the full amount of the available common resource is used. In addition, the crop associated with this strategy, is more resistant to water scarcity events, further enforcing playing safe in this strategy.
The applied solution of the Nash equilibrium does not provide a 'sign' towards which equilibrium will tend players. The risk dominance solution concept of this game results in strategy (defect –defect) dominating the strategy (coordinate-coordinate), with a frequency of choice near the 83% of the cases. Studies have also shown that increasing the riskiness of the payoff-dominant strategy favours risk dominant play, (Battalio et al. 2001; Dubois, D., Willinger, M., Van Nguyen 2009) and that players tend to defect in order to avoid loss (Rydval & Ortmann 2005). This solution concept has been used in the research as a reference for reasoning on the convergence of the players towards one of the two equilibrium. In our game players have more incentive to deviate, as there is a high uncertainty regarding the action of the other player.
Yet for both strategies an alteration of resource available due e.g. to climate change puts further pressure on strategic decision-making. Market and competition can also have an effect on farmer decision-making. The ABM model allow us further explore the interaction among agents and the variation in the equilibrium selection in spite of learning, risk aversion, resource variability.

Prediction: Farmers are backward looking and compare their strategy options retrieving results for both strategy choice from past payoff memory to make the allocation of crops on plots. For instance a risk adverse farmer is looking for the strategy option that can secure his payoff despite any external disturbances. In this case he turn to his memory and check the results, he then verify which was the strategy that ensured a low but secure payoff and decide which crop allocate on his land. Social uncertainty is explicitly included in the game underpinning agents' decision-making rule (stag hunt) , however they try to address coupled social and water environmental uncertainty by taking past payoffs as predictor of future ones.

Learning and information sharing*:* We have two models each one corresponding to two variants of learning. In the individual memory model agents employ an individual- level learning from its own past experience and we call it individual knowledge. In the collective memory model the agents rely on a social learning and share their results. The latter simulate a situation in which information are available to all agents.

Adaptation: the farmers adapt by converging on one of the two strategies, considering their knowledge, their information, their risk attitude and external disturbances.

Stocasticity: is used to reproduce water resource variability by means of normal distribution.

Observation: the model collects data on the role of individual knowledge, information and behaviours such as risk attitude to cope with unexpected water disturbances and social uncertainty. The model also evaluates the role of competition onto strategic decision-making.

Details

The model was implemented in Netlogo. The source code can be made available upon request. The model is initialized with two symmetric farmers that have the same initial wealth, number of plots and memory capacity. Their interaction represent the main part of the model while water, crops and market represent sub models and elements of the SES.

Results

Coping with social and environmental uncertainty with individual knowledge

The graphs in this section represent the water level on the horizontal axe and the risk aversion options on the vertical axe.

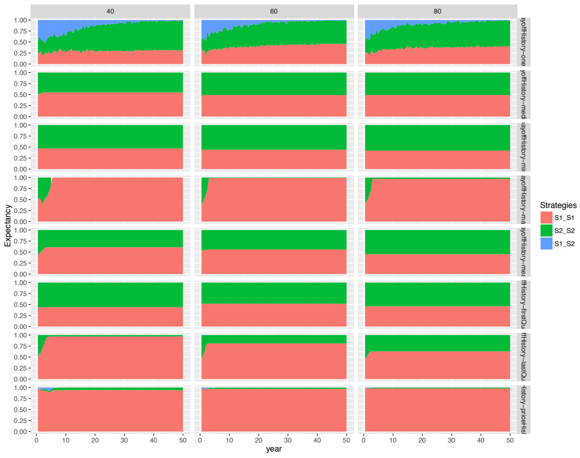

Figure 9 Individual memories fixed water 40, 60, 80 units

The game underpinning agents' behaviours depicts a convergence of agents towards the risk dominant strategy with a vey high frequency. This prediction is build upon a water level of 80 units. Using this result as a benchmark for comparison, in fig. 9 we observe that for this water level and a random selection of any of the payoff values in the memory, farmers experience social uncertainty and, as the interaction is prolonged in time and memory of past results is acquired, they converge toward the risk dominant strategy as also show by fig. 10.

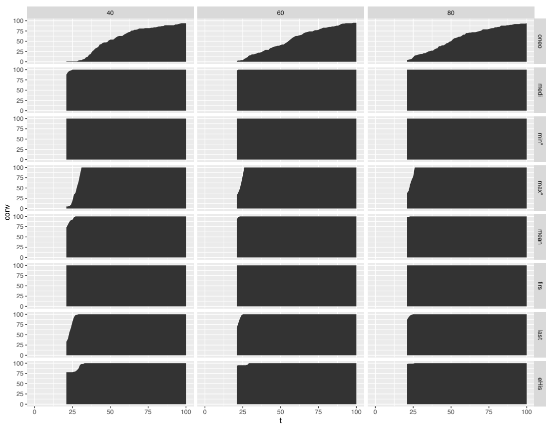

Figure 10 Strategy convergence individual memories for fixed amount of water 40, 60, 80

Introducing behavioural inputs of risk aversion give rise to a different narrative. Neutral attitude toward risk (mean, median, first quartile) results in a frequency of strategy choice near half and half. In addition agents do not take time to learn fig. 10 in 100% of the stochastic replications after 10 years, agents converge on the same crop allocation choice. When farmers are less risk averse, they largely prefer the payoff dominant strategy choice and after a short period of learning (they start with a frequency of choice of 50% for each crop allocation strategy), fig. 10 they rapidly converge on S1-S1. Agents do not experience social risk as soon as it happen that they choose S1 and recognize it as the best rewarding strategy. For decreasing but fixed level of water, we observe that in general agents increase their learning, switching more among strategy choices in the initial phases fig. 10. Furthermore the agents slightly tend to increase their preference for S1, as probably the crop in S2, which is more water demanding, generates lower revenues.

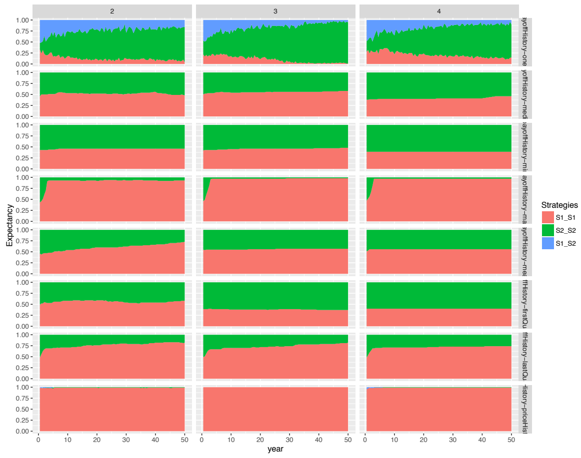

Figure 11 Individual memories with water uncertainty

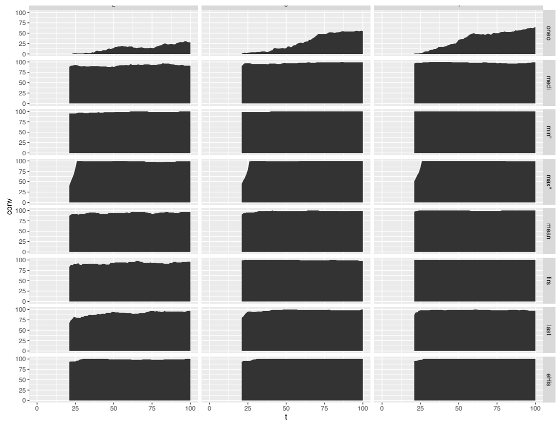

Figure 12 Strategy convergence individual memories with water uncertainty

When introducing the variability of the resource, we observe that, at the reference water level of 80 units, agents choosing randomly in their memory are strongly affected by the ecological uncertainty. The frequency of choosing the risk safe strategy augments in relation to the increase of variability in fig. 11. Yet the convergence on a similar strategy is also very difficult, agents switch between the two strategies and coordination get worse with increased variability fig. 12. Agents with different risk aversion also experience the effects of natural hazards. In general we can observe that a high variability push the agents towards the strategy S1._ Probably this is because for a limited amount of resource strategy S1 offers better revenues if farmers coordinate on the crop demanding less water to the system. In other terms they experience a reduced loss when choosing S1 and this strategy is perceived as less risky, on the contrary strategy S2, facing resource variability, increases the possibility for farmers to lose their yield and thus their revenues, augmenting the possibility of losses.

Coping with social and environmental uncertainty with shared information

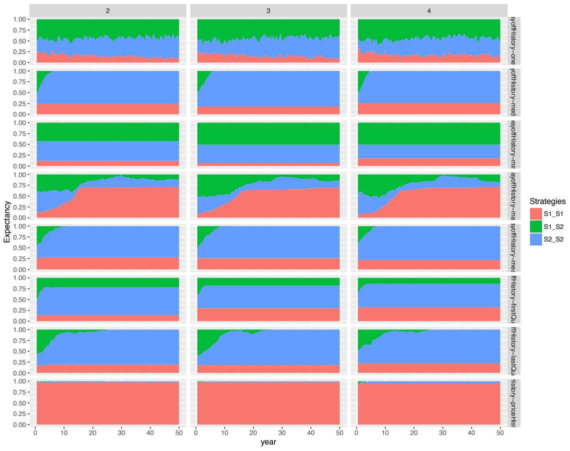

Figure 12 Collective memories and fixed amount of water 40, 60, 80

In the collective memory model, we observe very different results. In this model farmers can access the payoff obtained by both of them. In general we observe that agents experience way more social uncertainty and they prefer to choose more frequently the risk dominant strategy in fig. 12. Compared to the individual memory model even more neutral agents are preferring to coordinate on the risk dominant strategy with a frequency that is closer to GT prediction. In this case we presume that they consider strategy S1 very risky and they are afraid of losses. Yet we can presume that for fixed but lower water level the risk of losses, related to the choice of a more water consuming crop, increase and the farmers are more prone to choose the strategy giving better payoff, thus moving the farmer towards the payoff dominant equilibrium.

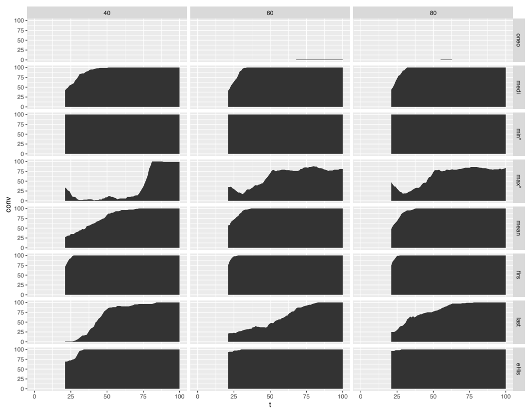

Figure 13 Strategy Convergence collective memories and fixed amount of water 40, 60 , 80

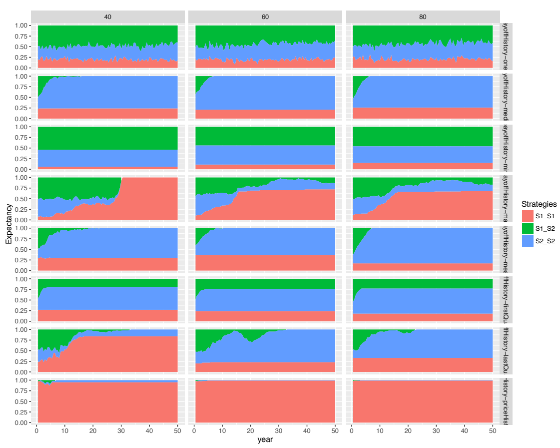

Figure 14 Collective memories and water uncertainty

When introducing environmental uncertainty we observe a change in the tendency described above. Ecological uncertainty is probably reducing the gap between the payoff of S1 and S2, as coordinating on S1 allow to use less water in the system and it has a larger share of dry crop, making S1 a more attractive possibility to maximize their income. This could also explain why for lower but fixed level of water we observe an increased frequency of S1 choice in fig. 14. Sharing of information is also generating more switches between strategies and farmers experience more learning compared to the individual memory. This is evident for less risk averse agents, but not for more neutral subjects fig. 14. The farmers choosing randomly are the one more affected by the share of results. It is very difficult for them to converge and they respect the random choice probability 25% (S1), 25%(S2), 50% (S1/S2) fig. 15. Subject to water variability the social learning agents substantially respect the same frequency of choice that we observed for 80 units of water level in fig. 15. Even in terms of convergence results do not change in face of water variability fig. 15. We can presume that the payoff dominant strategy still bears a lot of riskiness. Agents experience a high level of social uncertainty that does not change with greater natural hazard.

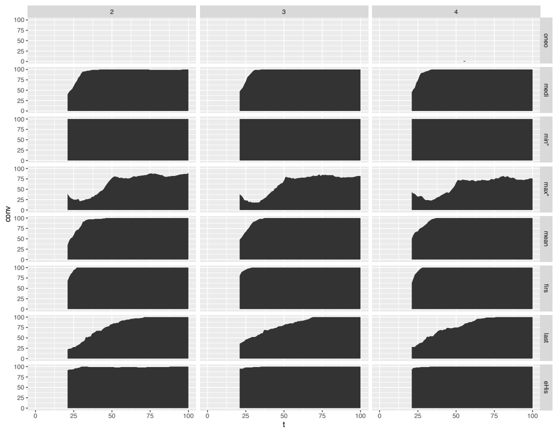

Figure 15 Collective memories and water uncertainty

5.2 An agent based integrated assessment of water uncertainty for Consorzio di Capitanata

WAT –DEMAIN (WATer DEcision MAking and INteraction) is a model developed to provide Consorzio di Capitanata with policy recommendations of possible future water governance scenarios considering policy tools, variables and factors in face of hydro-climatic hazards. This model represents the implementation of the initial conceptual model.

Consorzio di Capitanata did not yet experienced a reduction of the quantity of water available for primary production, but is well known that the Mediterranean basin is a climate change hotspot (Diffenbaurg and Giorgi 2012) in which very likely an increase of temperature and dry days is expected through out the 21st century (IPCC 2014). In this regard Puglia is exposed to climate change effects and especially to increasing temperature, heat waves, drought and sea level rise as it well reflects conditions of the Mediterranean region. Vulnerability concerns are growing as the economy is largely dominated by agricultural production, and irrigation activities could soon compete with other economic sectors. As a matter of fact, today, there is an urgent need to evaluate the sustainability of existing policies against possible hazards as well as to include more integrated reflections on variables and factors influencing water governance. Insights could easily fit into integrated adaption measures reflections for future water policies and plans.

The role of Consorzio di Bonifica della Capitanata and of its members

Consorzio di Capitanata is a public authority in charge for design, operation and maintenance of reclamation infrastructural works. The infrastructures belong to the state and the region. It also concurs in the implementation of actives related to soil defence, managing and use of water resources for socio economic rational development. The Consorzio covers an area of 441.000 Ha and span over 39 municipalities of Foggia province.

The Consortium is composed of members that are all those property owners paying a fee to the consortium. The fee covers maintenance, running and custody of infrastructural works and the general functioning activity of the consortium. The fee is proportional to the benefit received by each property owner. A document called *Piano di classifica* identifies technical and economic parameters to quantify the benefit for each member and establish the right fee amount with a transparent approach based on a commonly agree institutional rule for the power assigned to the consortium by national and regional laws.

The members elect the administrative body of the consortium and actively participate to its functioning. Elected candidates are member of the consortium.

Irrigation activities follow a specific designed rule "Regolamento per l'utilizzazione della acque a scopo irriguo del comprensorio", this rule has been update in 2015. Water is provided between 1st march til end of November of each year. A water distribution plan is

issued every year based on total water available. The quantity of water in the basing is communicated and constantly updated on the website.
The water is distributed exclusively to Consorzio's members (or to user with specific contracts), that comply with the presentation of a formal request of water and that has received authorization by the Consorzio.
In case of unexpected events is the Consorzio that regulate changes in the normal water distribution and set up turn.
The Consorzio monitor water consumptions and verify the integrity of water measuring systems. In case of damages, freeriding, failure to pay the fee is responsible to administrate the sanction, which can be, in very serious cases, the suspension of the right to receive water. But members are required to communicate any variations or to collaborate by reporting any damage to the public infrastructures.
The Consorzio also establish the necessary quantity of water for each crop. In the document "fabbisogno irriguo delle culture"[1], the consortium informs members of the range of water that can be required for each crop allocated on their lands considering climate change variation and suggest both on best technology and best consequent water distribution per growing phase of the crop.

In line with the approach of this thesis, the robustness of Consorzio di Capitanta has been evaluated against the design principles (Ostrom 1990). Results show that the consortium is a robust institution. It is well nested in both national and regional law. The regulation is clear, rights do & don't are recognized, boundaries and membership are well defined. Members are actively involved in the administration of the Consorzio. There is a monitoring and enforcing system in place. The functioning of the Consortium is covered with membership fees that in turn receive operation, maintenance and monitoring.

Design Principles	Consorzio di Bonifica Capitanata
1. Defined boundaries & membership	Yes
2. Congruent rules	Yes
3. Collective choice	Yes
4. Monitoring	Yes
5. Graduated sanctions	Yes
6. Conflict resolution mechanism	Yes
7. Recognition of rights	Yes
8. Nested enterprises	No
Institutional performance	**Strong**

Table 1 Robustness of Consorzio di Capitanata

[1] Fabbisogno irriguo delle culture available at http://consorzio.fg.it/index.php?option=com_content&view=article&id=49:fabbisogni-irrigui-delle-colture&catid=37&Itemid=111

Model Description
This model consider the above information and it is developed starting from previous model introducing the following assumptions to cope with the real case:

- The game in the model is fully symmetric (same probability for each strategy, same production function and conditions: land, costs, prices and same payoff per strategy), both crops can be simultaneously produced.
- Agents are in a network and the game is played in pairs in the network.
- The agency introduces water policies. Three levels of water costs. This levels correspond to 3 block tariffs being the first one a positive incentive and the third one a punishment.

This set up isolate the decision-making of agents with reference to water availability and it is functional to shed lights on factors and variable influencing the evolution of cooperation (or not) in face of hydro-climatic hazards. This baseline scenario is expected to privilege the defecting convergence, in particular with increasing water scarcity: punishment alone is not enough to ensure the evolution of cooperation. The simulation scenario will analyze if direct reciprocity can represent a complementary mechanism to evolve cooperation and the role of network that will be enlarged.

Water for irrigation: Water availability for irrigation purposes is determinate at the initialization of the model. Water availability for each farmer is a parameter provided to farmer by the agency (Wp). Each farmers compute its water need (Wi). if the sum of water requested by the farmers is less or equivalent to the total Wp in the pond, each farmer will receive Wi required. In case total farmers Wi exceed Wp then the agency decide to assign Wi proportionally.

Stocasticity: is used to reproduce water resource variability by means of normal distribution.

Crop functions: to realize the study experimental data have been gathered from local productions of tomato and sugar beet. The production function in the model is derived by the fitting Mitscherlich's equation modified by Giardini and Borin. The curve response parameters have been calculated using experimental data of yield responses to irrigation obtained in the different years in Southern Italy. This equation was originally developed for Consorzio di Capitanata to study optimal allocation or irrigation water among 9 possible crops (Rubino et al 2008) [2].

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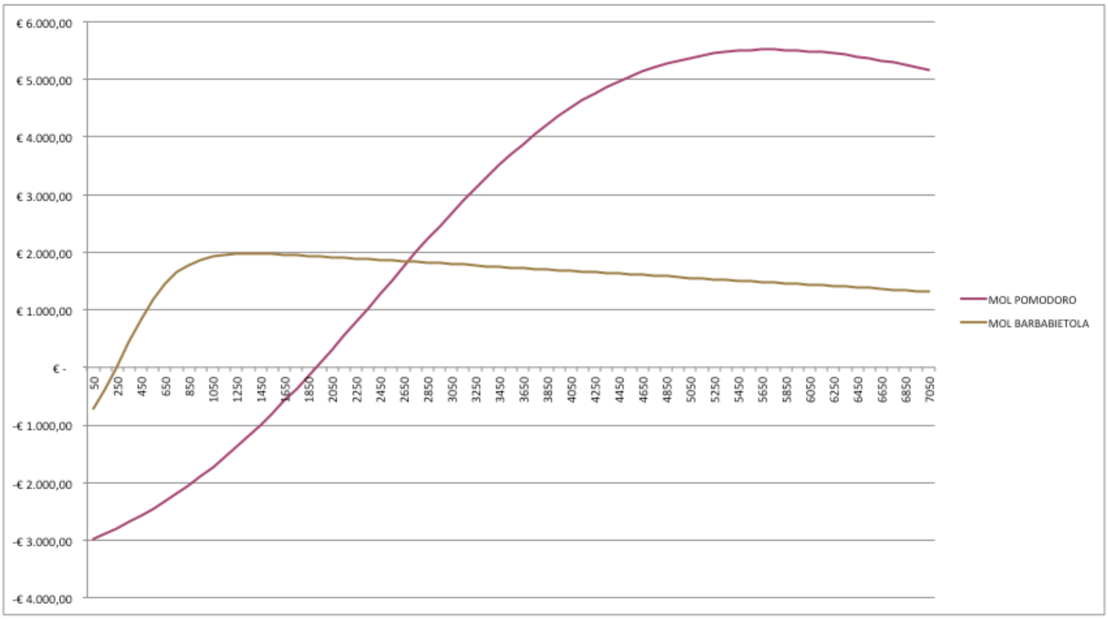
[2] Optimal Allocation of the Irrigation Water Through a Non Linear Mathematical Model Pietro Rubino1*, Maurizia Catalano1 , Roberta Rana2 , Angelo Caliandro1 1 Dipartimento di Scienze delle Produzioni Vegetali, Università di Bari Via Amendola 165/A, 70126 Bari, 2008

The production function used is

y=A[1–10^–c(b+x)]·[10^–k(b+x)2]/[1+10^–c(b+x)]

where:
A is the maximum potential yield, in t ha-1;
b is the volume of water available per ha for the cropin natural conditions, in m3 ha-1;
c is the coefficient of increase, indicating the rapidity of achievement of the maximum yield, in ha m -3;
K is the coefficient of depression, indicating the tendency of the yield to decrease after the achievement of the maximum value, in (ha m-3)2;
x is the volume of water applied per ha under specific experimental conditions, in m3ha-1.

This is the resulting curves of the two crops' production functions. In the model C1 is tomato while C2 is sugar beet.



Interaction: Farmers make their choice based on water available and can choose between 4 cultural plans (cultivation plans for 3 ha):
C1C1C1 if Wp between 80-100%
C1C1C2 if Wp between 60- 80%
C1C2C2 if Wp between 40- 60%
C2C2C2 if Wp <40%

Once the farmer has completed the choice for the cultural plan he then demand water Wi to the agency and can demand water according to its type of strategy:

- Defecting strategy (Wid demanded correspond to an experienced amount of water - chosen from the memory / production function - necessary to grow the crops)
- Cooperative strategy (farmers prefer to ask for a reduced amount of water Wic for each Ha (e.g. Wi -10% = 0.9 Wi) and receive a reduction in the cost of water)
- Cheating strategy (the farmer ask an amount of water Which to reach the maximum yield of the crop)

These strategies correspond to the possible agents' actions.

In the model we have a population n/4 of famers each population correspond to 1 (cheating), 2 (defecting), 3 (tit-for-tat) according to type.

To progress the interaction of agents in the model:

- Cooperative strategy, the pro-social behaviour, is eliminated from the set of possible strategies, because for first observations it has been observed that this pro-social behaviour is dominated by both defecting and cheating strategies. Thus in the progress of the model the three available strategies are:
  a. TIT-FOR-TAT strategy is introduced: each agent starting from an initial strategy will face the other agent and modify accordingly its strategy, if no previous strategy is recorded from the other player, defecting is baseline action and it's the initialization strategy.
  b. Cooperative strategy (Wid demanded correspond to an experienced amount of water - chosen from the memory / production function - necessary to grow the crops)
  c. Cheating strategy (the farmer ask an amount of water Which to reach the maximum yield of the crop)

With this set up agents can only play two actions either cooperating or cheating.

Agents compute production from each plot.
Agents compute the net payoff. First they compute the gross payoff from production assuming the selling price =1, then subtract the cost of water according to the three levels of water cost (punishment) + incentive (reduced amount of water) net payoff

- How the cost function works:
  There are three level of water cost (c1, c2, c3).
  For an amount of Wi^c =L the cost of water is L * c1 (c1=c2-10%)
  For an amount of Wi^d =L1the cost of water is (L*c1) + ((L1-L) * c2)
  For an amount of Wi^{ch} = L2 the cost of water is (L*c1) + ((L1-L) * c2) +((L2-L1) * c3)
  In case of reduction of total water availability, the cost function decreases proportionally in order to keep the same levels of prices

Strategy Evolution: Each time agents are playing in couple. Each agent has its p_evo (the probability of strategy evolution = 0,05% that allows for a slow strategy modification), then the agents observe the neighbours payoff and opt for a change accordingly to the best payoff observed.

Results

The analysis of the model corresponds to three scenarios. For each scenario two hypothesis are tested a) evolution of strategies with an increasing level of discount, b) evolution of strategies considering increasing level of water scarcity.
The number of players is 600.

Firstly we developed a *Scenario A- Baseline*, in which the three mentioned strategies Cooperatives (get a discount of 10%), defecting (ask for what you deserve), Cheating (Wi-maximizing production on water base that is potentially available) are explored against the two hypothesis.
Secondarily in the *Scenario B- TFT4* we introduce a behavioural perspective enabling agents to paly a TIT-FOR- TAT strategy. Agents plays in a network of 4 the following three strategies Cooperatives (ask for what you deserve), cheating (ask all the water you need to maximize production), TFT for each interactive partner see what he did at first, and the copy (reciprocity with neighbors 4). The two hypotheses are thus tested considering the role of behaviours.
Thirdly the *Scenario B- TFT8* in which the same setting as scenario B is maintained but the network is enlarged to 8. In this scenario the growing of the network mimic the increasing of information available. The two hypotheses are thus tested considering the role of behaviours coupled with an higher level of information.

In the following section only the most relevant graphs are reported, the full analysis is available in the annex. The full spectrum of analysis considers both actions and strategy parameterizations. This has been extremely useful to carefully interpret the results

Scenario A- Baseline

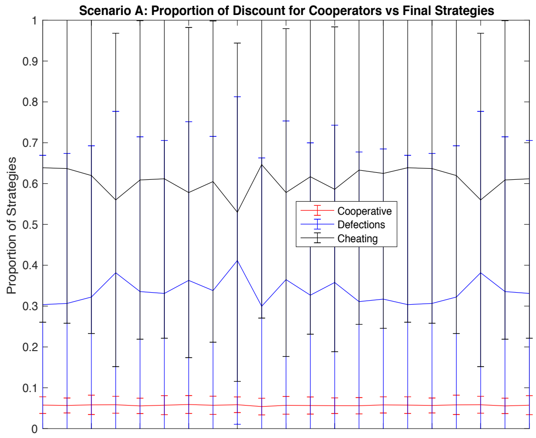


Figure 16 Scenario A, discount effect on strategies

Figure 16 describe the increasing of discount from 0 to 1 in relation to the three strategies. Reading the results from left to right we observe that the increasing of discount is not affecting the strategy choice. It is also visible that discount does not have any influence on the evolving of cooperation and that cheating and defecting dominates cooperative strategy

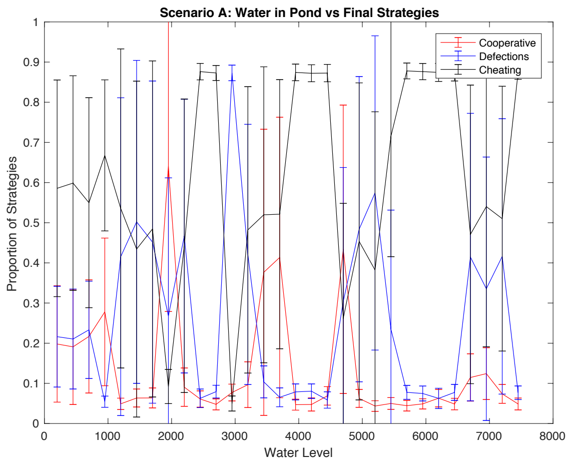


Figure 17 describe the effect of increasing water scarcity from right to left in relation to farmer strategies. It is possible to observe that cheating is the prevailing strategies that cooperation is possible for decreasing level of water but it is punctual and not significative as before and after this point (corresponding to water at 2000, 3500 and 4500) there is high variability of strategy choice. The variability of strategy choice in fact increases for lower water level.

Figure 17 Scenario A, water scarcity and Strategies

Results

Results highlight that cheating and defecting are dominating cooperation and that the strategy choice is not affected by the incentives, as the lines are not showing any variation from the horizontal at the increase of the discount. When we add water variability it is possible to observe the effect of decreasing water level on strategy choice. Water scarcity seems to push the equilibrium closer, the lower the water level the more possibility of switch strategy appears. It is possible to relate this to closer payoff values as well as to network relation that are favouring cooperation as co-operator are closer. Also small variation in water quantity can produce strategy variability as in several specifics point, picks highlight that there is a complete switch of strategy choices. Yet equilibrium are mixed.

Scenario B- TFT4

It is worth to recall that in this scenario the agents have only two possible action (cooperating and cheating) and three strategies as TIT for TAT is introduced. See section Model description and agent interaction for complete information.

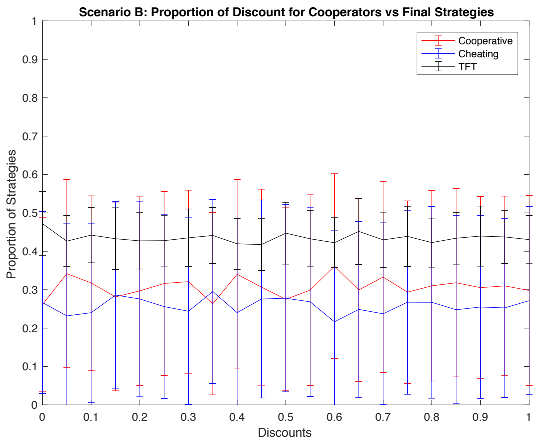


Figure 17 Scenario B, discount effect on strategies

Figure 19 Comparing scenario A with B it is possible to observe a change in the figure. Cheating is still the dominant strategy but the capacity of agents to observe other people actions is pushing the cooperative strategy higher. There is an increased probability to make a cooperative choice. But the lines are still horizontal showing no sign of being affected by the growing of the discount

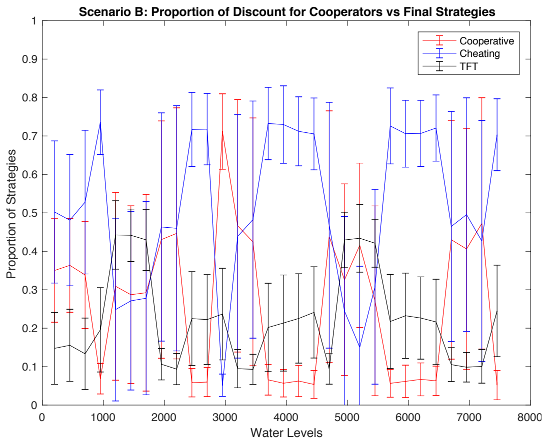


Figure 18 Scenario B, water scarcity and Strategies

Figure 20 Comparing scenario A with B, it is possible to observe that there are still multiple equilibrium, cheating is still dominant but cooperation is growing. In fact the probailist choice of cooperation increases as well as the probability of cheating is reduced of a percent point from 0,9 to 0,8. From left to right we can notice that higer level of water are favouring stable and dominat equilibrium, while from righ to left diminishig amount of water are increasing choice variability and reducing the distance between the equilibrium.

Results

Results highlight that cheating is still the dominant strategy, probability of cooperation is growing in comparison with the same graph o f baseline scenario and for reduced amount of water there is high variability of choice and cooperation emerge as a possible solution. In this scenario cheating and cooperation appears as multiple equilibrium. Thus reciprocity and the possibility to see the other player choice is influencing the decision-making and reduce water availability is also creating a space for choice variability

Scenario C- TFT8

In this scenario agents play in a network of 8. The level of information is increased.

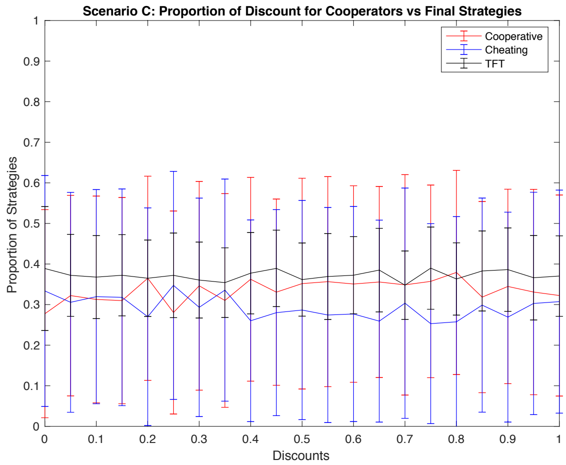


Figure 19 Scenario B, discount effect on strategies

Figure 21 Comparing scenario B with C it is possible to observe a further evolution in the strategy choice. There is an amplification of the phenomena observed in B. There are still multiple equilibrium but cooperation is further increased. For the first time we can observe a change in the dominant equilibrium, which is now cooperation, when the discount is over 0,4.

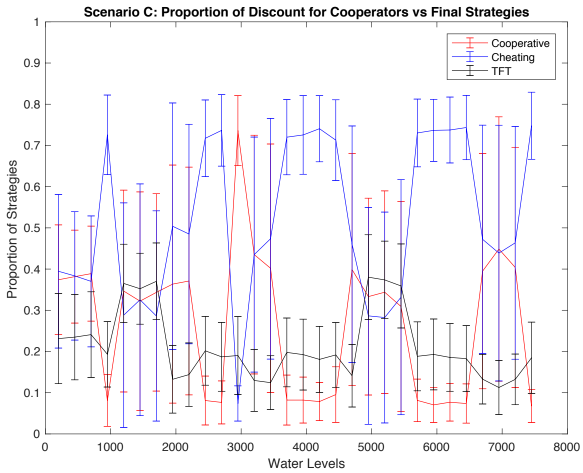


Figure 20 Scenario B, water scarcity and Strategies

Figure 22 Comparing scenario B with C, we can observe a slow tendence to furher reduce the choice of cheating and its picks, a slight increase fo cooperative choice probability. Even more closer equilibrium for low level of water availability.

Results

This analysis confirms that reciprocity is affecting strategic decision-making and that an increased number of network members that share information support the cooperative behaviours. Further to this it is also positively influencing the discount, which is now producing some effects favouring the evolution of cooperative behaviours. This analysis also confirms that when more co-operators are closer it is easier for cooperaiton to be mainteined. In the experiment with water scarcity it is possible to notice a slight increase in cooperative choice making. But this tendency should be further verified enlarging further the network. Further analysis are provided in the annex 3.

In a table 3 we provide main findings in relation to the case studies, the dimension and the variables analysed.

Case studies / Variables		Lebanese WUA	Farmers model	Consorzio di Capitanata
Uncertainty	Effect of water variability	X	X	X
Policy	Effect of incentives	X		X
Information	Effect of collective memory		X	
	Effect of network size			X
Behaviours	Effect of Reciprocity		X	
	Effect of risk aversion			X
	RESULTS	Variability reduces payoff and incentivize freeriding. The right amount of sanction restore a payoff condition making cooperation more profitable	Safer and self-interest driven choice is preferred. Larger amount of information increase this tendency. Lower and neural risk attitude favour cooperation to emerge	The maximization of payoff and cheating is the preferred option. The incentive is not producing the desired effect unless information on other water users choice is made available. The network and its size is also reinforcing the cooperative behaviours Water scarcity reduces the difference in the values of payoff and cooperation becomes a feasible solution. This tendency is supported by information and the network

Table 3 Summary of main results

6 Discussion

6.1 The fragile potential of Lebanese local water institutions to respond uncertainty

Water issue represents a thoughtful challenge for Lebanese agriculture and food production and, because of the climate change, it will probably and increasingly affect farmers' and established WUAs' behaviour and outcomes: their choices will play a pivotal role in influencing the resource availability and distribution. In this context, the study provides a deeper knowledge on the major enabling and constraining conditions that lead to the success and/or failure of their associations (WUAs) in implementing and adapting water governance and management schemes.

Despite the current post-conflict phase and the slow institutional reforming process that characterize the country, findings identify the Lebanese local associations – WUAs – to be a potentially suitable form of participative organisation to foster a better governance and management of water resources at secondary and tertiary irrigation schemes level, and to enhance Lebanese farmers' livelihood. The results achieved through the IAD analysis highlight that the success of the WUA depends on the ties among community members as well as on the understating of the mutual benefits that joint governance and management as well as cooperation can produce. Information and awareness raising campaign are also playing an important role to ensure commitment of farmers towards WUAs rules. However, different and new governance initiatives and actions still need to be investigated in order to boost farmers' capacity building, especially in light of the fact that, up to now, driving forces to WUAs creations were NGOs, International Donors as well as Lebanese conscious officials.

Nevertheless, Lebanese local institutions are fragile and exposed to failure, as they do not encounter relevant design principles. The lack of institutional recognition and of subsidiarity, the uncertainty of operational (supervised) autonomy, and the exclusion from decision-making process for irrigation water governance and management at different levels, mine their robustness. Given the missing specific regulation and the incomplete institutional reform, each WUA is forced to decide its own institutional settings, mainly to act as a cooperative, while leaving great uncertainty over their future arrangements and operational discretion. Furthermore, some of the operational rules and water allocation agreements date back to the ottoman period and no one is posing it in serious discussion, possibly limiting the WUAs capacity to adapt them to changing conditions facing this intrinsic stiffness. However, where WUAs are operating and filling the institutional gaps, irrigation water use proofs to meet the producers' requirements. Thus it can be derived that inadequate coordination among central and local bodies, lack of governance, and mismanagement in Lebanese rural areas appear to be some of the major causes behind water scarcity. Finally, WUAs should be given the possibility to change their statutory and operational rules especially with regards to their enforcement systems, as it could be applied as an adaptive governance measure favouring their robustness as well the capacity of the irrigation systems to cope with expected water scarcity and to avoid in-depth consequences.

On balance, WUAs represent vibrant entities that need a clear normative recognition (Anderies, 2004), and that should evolve as local institutions able to provide governance frameworks, incentives and knowledge for farmers in order to foster their capacity to cooperate and, in the meantime, to reach a higher degree of competitiveness. However, the assumptions and the results achieved by the study entail further researches and quantitative assessments. In particular, additional analysis are required to explore the role that local governance solutions, incentive schemes, organizational, technological and social innovations can play when changing economic conditions and environmental challenges emerge, and to evaluate the deriving impacts on the local institution robustness and resilience and on farmers' behaviours and awareness.

6.2 The role of information and behaviours to cope with uncertainty

The design of our theoretical model, and its application to the case study underline the importance of the adopted systemic thinking. This approach allows at focusing on considering uncertainty, information and behavioural effects on coordination in the management of natural resources. Results are coherent with the GT assumptions, and the frequency of the strategy choices that emerges from the analysis of the random phenomena are in line with the probabilistic hypotheses. The simulations show that decision-making is strongly influenced by social uncertainty as the risk dominant strategy results highly preferable. Natural hazard is pushing the agents towards more coordination if faced with the possibility to limit their losses, thus reducing a better gain opportunity makes the cooperative choice a possible solution, but agents experience frequent variability in the choice of the strategy. Behaviour in the form of risk aversion is also influencing agents' choice, in fact risk seekers and neutral agents are prone to make more frequently coordination choices. On the contrary, collective learning has increased the preference for safer behaviours. In the collective learning setting, farmer can choose from a larger pool of result, this set up has generated more switches between the two possible strategy and agents reach coordination after more learning attempts. Yet in the collective knowledge setting, agents and their behaviours seem slightly affected by natural hazard, in fact when ecological uncertainty is introduced it is possible to record an increase in payoff dominant choice. Probably a reduction of the gap between the two payoffs is behind this situation.

The model design for the Consorzio di Capitanata confirms the importance of the systemic approach that includes both uncertainty and the interrelation between factors and variable (reciprocity, network, incentives) when exploring decision-making. This approach allows to discovering synergies to cope with unexpected resource variability. This model is a first attempt to provide insights on the role that incentives, information and behaviours play on the governance of water common resources. In fact, Consorzio di Capitanata can expect an increase in free-riding attempts in case of high water variability when incentive is the unique measure in place. The increase of water price is not enough to prevent cheating behaviours as well as the punishment is not granting any change in non-cooperative behaviours. But when the incentive is supported by the diffusion of information concerning previous choices, then it starts producing the desired effect of coordination as the preferred choice. Furthermore water scarcity creates the condition for cooperation to emerge as a possible solution due to the fact that payoffs are closer and that the group is supporting cooperation. Information, reciprocity and group size showed some positive effect on strategic decision making favouring cooperation, but this observation requires further investigations with a larger group of members in the network prior to be confirmed.

6.3 Limitations and further research

At this stage of the research, the model was deliberately kept simple to approach human decision-making in social ecological systems. It contributes a basis for studies aiming to explore in a systemic way a) the enabling and constraining factors of coordination in irrigation systems, b) equitable and efficient distribution of water resource and c) policy effectiveness. Thus additional elements that could enrich the model and influence strategic decision-making are:

- Technological innovation that could produce a shift in the production function, thus influencing the evolution of strategies. With the introduction of this factor we can further observe the propagation of innovation.
- Network enlargement to verify the robustness of the tendency of network supporting the evolution of cooperation and its positive role for farmers to cope with water uncertainty.
- Introduce a larger number of products to verify the existence of a relation between cooperation and specialisation (diversity).

Limitations are due to the model simple framework. A first remark is that the model of Consorzio di Capitanata can be further expanded to depict the reality of the consortium with GIS cartography and geo-references of consortium members. This work could be the object of a specific project to create an instrument for simulation in the hand of the Consorzio. A second remark is that it will be possible to introduce climatic maps to increase model representation of reality. Thirdly a choice was made on factors and variables among the most relevant in the literature. But other could be explored like leadership or moral and ethical standards.

7 CONCLUSIONS

The governance of available water resources in irrigation is among the most pressing societal challenges. A growing global population and an increasing variability of the resource, especially due to projected climate change impacts, is endangering the sustainability of food systems. To cope with this situation water institutions self-governance is gaining further attention as technological solutions alone have proved not to be sufficient. Yet today how levers can be activated for farmers and their institutions to cope with water rapidly changing condition, to target collective action potential and stimulate self-governance adaptation capacity is far from being understood. To fill this gap the approach proposed explicitly includes uncertainty of water resources and analyse farmers responses in combination with rules in use, information and behavioural factors.

This research stems from the fact that a new vision is gaining attention both in the domain of common-pool resources research than in the food systems governance study. A vision that refers to community level and micro-level as the emerging domains of analysis to investigate the occurrence of behaviours and collective action. This vision considers farmers/ water users as drivers of change towards sustainable use of water resources and thus also to food sustainable transition. Furthermore with that focus, farmers as driver of change, the present study embraces the science of complexity. It considers the socio and ecological systems as "adiacent possible" and presents how information can contribute driving the evolution of collective actions coping with ecological variability.

To accommodate this vision in relation to the complex dynamics of coupled socio-ecological systems under uncertainty, I propose an agent-based model that combines conceptual theories with details of a real case study. This approach allows generating understanding of a potential social dilemma situation (and its responses) that goes beyond the case, to shed light on the emergence of cooperation and its evolution for a farming community. In fact theoretical water dynamics and theoretical influential variables like reciprocity are grafted over specific contextual aspects like rules in use and irrigation water usage for two specific crops. The present research and its methodology actually aim demonstrating the relevant role of social variables for the management of a scarce resource and the importance of this understanding to shape governance adaptive policies. This approach is quite innovative in the field of both the study of SES than of food systems and sits in between the typical use of agent-based models on either only theoretical or only depicting the case studies, offering the opportunity to generalize a context specific social dilemma. In detail the model proposed intend to shed light on a) the emergence of cooperation among famers under uncertainty and b) the role of policy, information, behaviour to cope with unexpected disturbances like water variability.

The developed model shows that research and interventions tackling collective action and social dilemma in the management of water resources should:

a) Explicitly include uncertainty related to the decision-makers. This uncertainty refers to both social trust and variability of resources,

b) Adopt a systemic thinking approach, spanning multiple domains and including several factors and variables to achieve responses leading to better phenomena understanding.

Preliminary findings seem to show that:

- Risk-averse and self-interested choices (non cooperative) emerge among farmers in response to uncertainty (both social than environmental).
- Information can increase choice variability. But we recorded that specialization of information is decisive. Collective memory on past payoffs under resource variability increase the probability of non–cooperative behaviours, of playing safe. While the information on the other player choice, in a tit-for- tat environment, push the agents towards increased cooperation.
- Behaviours are relevant variables and affect strategic decision-making. As expected, lower risk aversion favours the emergence of cooperation, on the contrary high level of risk-aversion increases the probability of playing the safer option. But mainly reciprocity influences the decision-making, pushing cooperative behaviours at the expenses of non-cooperative ones.
- Incentive policies alone are not sufficient to prevent farmers to make self-interested choices, but if coupled with information the incentive policy can produce the desired effect of enhancing cooperative behaviours.
- Networks and its size are also playing a role, a larger network and reciprocity can convey information and support cooperation.
- The model also showed signals that occasionally for lower water levels cooperation can emerge as a possible choice option, it is presumed that self-interested choice gains are not far from more cooperative ones, yet this observation requires more accurate analysis.

However these observations should not be conceived as stand-alone, but as part of a larger picture. The feeling is that food policy studies and water resource studies have not yet taken the full advantage of both traditions. We suggest that the management of water resources and farmers/water users are a common ground that could support complementary research regarding community development efforts and that the study of these efforts should go in the direction of better understanding on the role of information and behaviours in both domains with a synergistic approach.
For example considering food systems sustainability, the *new food equation* (Morgan & Sonnino, 2010), that refers to the combination of highly complex developments as climate change effects, food price surge, food security, land conflicts and rapid urbanization, fails to accommodate uncertainty, especially water uncertainty and farmers responses, as relevant dimensions. In this regard research in this field should progress in the larger domain of food-integrated policies that ensure a sustainable transition to the food systems of 2050, by considering water users behaviours under uncertainty. While the indication for Consorzio di Capitanata is to test by means of experimental economics on the field the observation relative to the specialization of information coupled with incentives to sustain their adaptive policy development to cope with water variability.

Reflections could also be done on the productive sector and the crops including water – fed crops and how this can help the transition towards more sustainable food system. In the case of Lebanon and for the existing water user association, that proved to be successful institutions, the research support the request for official recognition of these self-governing institutions, as this is the main factor halting their robustness.
This work and the methodology used provide a basis to continue the reflexion of decision-making under uncertainties and evaluate factors affecting the governance of water resources to sustain future food system. The process of contextualizing irrigation water dilemma triggers both theoretical than empirical questions: can different varieties less water demanding be produced? Will the farmer cooperate changing their productive systems? What kind of incentive could support a transition towards more sustainable primary sector production? Will different context trigger different responses of water users?

In view of the above, it is recognized the big potential of complementary research to achieve understanding of self-governance capacity of commoners to cope with the unknown and the evolution of collective action for adaptive policy development. Nevertheless the model should be enriched with an enlarged network to further confirm the tendencies illustrated and results should be further tested in laboratory or with field experiments before being validated. The model could be further expanded introducing climatic maps and geo-referential data on farmers and water infrastructures to respond reality needs. Moreover technology could also be introduced and its effects observed.
To conclude it seems that social elements and collective actions should be considered in the development of adaptive policies. Information and behaviours seem to influence social dilemma outcomes and any governance development should make an extra effort to include those elements in their reflection on policy development. However further research work in this field is required as well as inter-disciplinary approach to address system complexity to gain proper understanding of actual effects of policy options on coordination mechanism under uncertainty.

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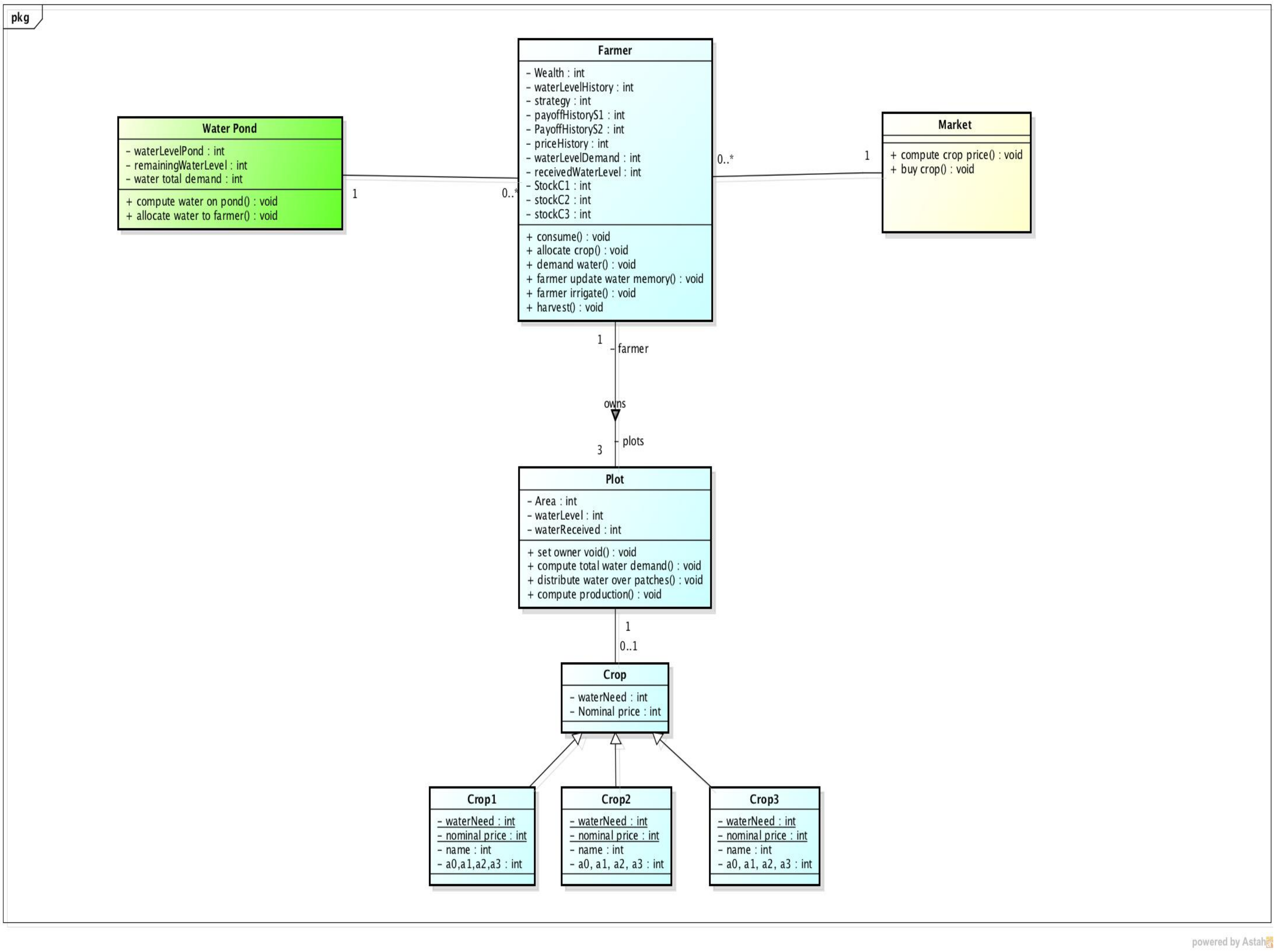
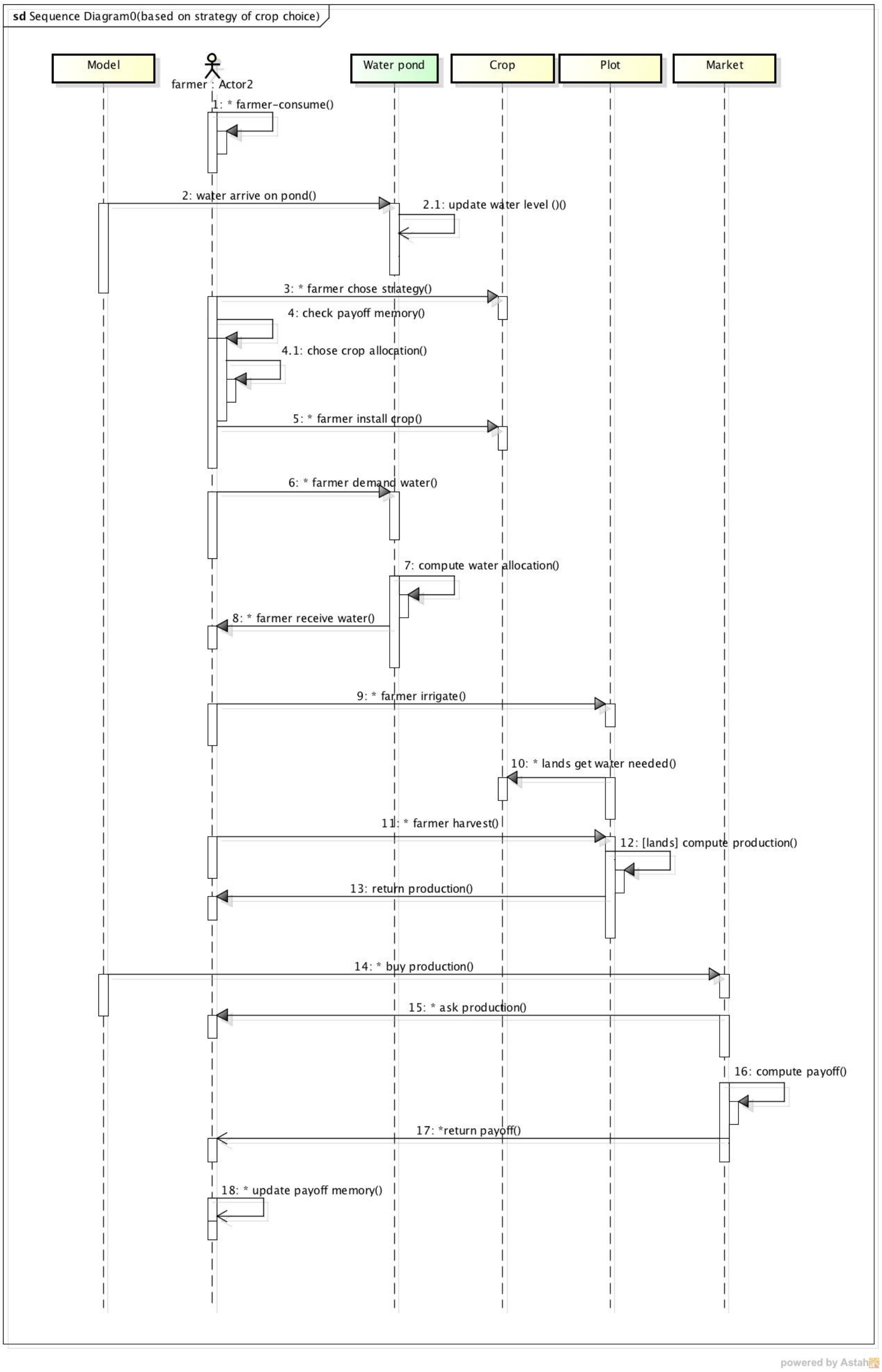
9 Appendix

Appendix 1 Class diagram and entities



Appendix 2 Sequence diagram



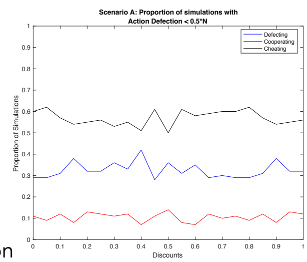
Appendix 3 WAT-DEMAIN model analysis

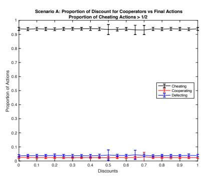
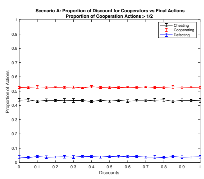
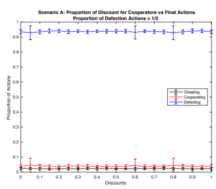
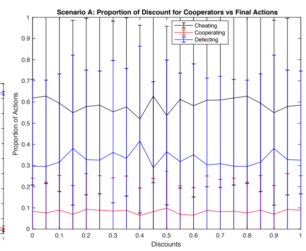
For each scenario, two hypotheses:
a. increasing level of discount
b. increasing level of water scarcity
N = 600

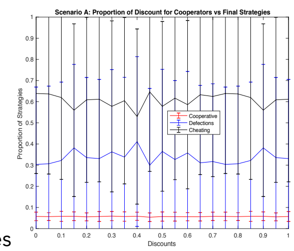
SCENARIO A - BASE

3 strategies:
Cooperatives (get a discount of 10%), defecting (ask for what you deserve), Cheating (Wi- maximizing production on water base that is potentially available)
3 actions:
Cooperatives = lower consumption of water and off
= Defecting chose consumer / historic water
Cheating = water consumption maximizing the payoff

SCEARIO A discount

action 

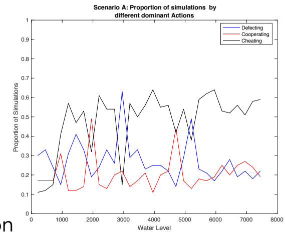
strategies 

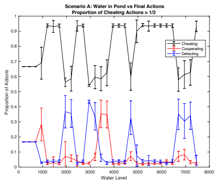
The strategy graph shows that cheating and defecting are the dominat strategies and that cooperation is not influenced by the increasing of the dicosunt (from left to right).
Actions and the details of equilibria show a clear polarized equilibria with clear dominat action.
In general terms (from right to left):

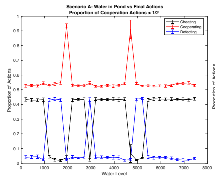
- punishment and incentives are not enough and does not affect strategies and actions
- cooperation is not favoured by punishment and incentives

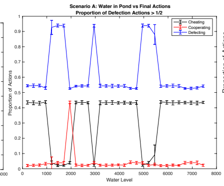
1. cheating and defectiona are on cooperative opitons emerging

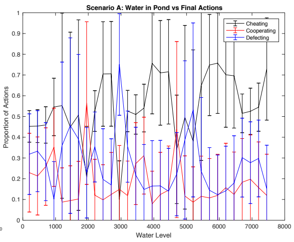
SCEARIO A water

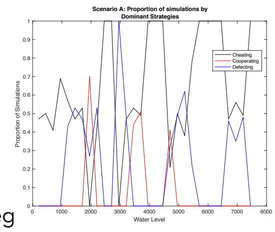
action 

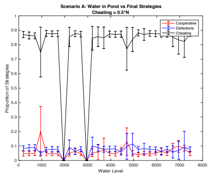


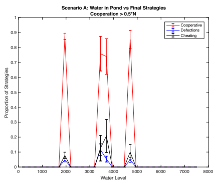


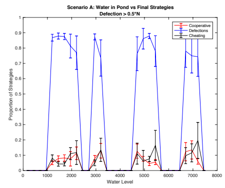


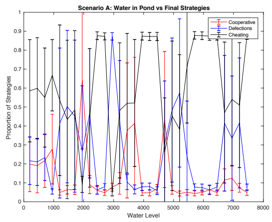


strateg 









In the strategy graph, from right to left ,we observe that a decreasig of water resource is influencing the stretgy choice. We can observed mixed equilibria and from right to left the augemntation of strategies and actions variability

1. reduction of water variability increse strategy variability, especially for small a reduction in the amount of water. From right to left we also observe diminishing proportion of strategy choice and closer equilibrium values, probably the payoff are closer and the interaction and the network relation are favouring cooperation pics.
2. cheating is accopanied by an increasing value of defecting;
3. punishment and incetive are not enough to support cooperation.

We observe picks but they are not representative of a certain action choise as before and after there is still variability, we can presume that for the specific values, in some cooperative set the cooperator are close to each other in the network.

SCENARIO B - TFT

3 strategies:

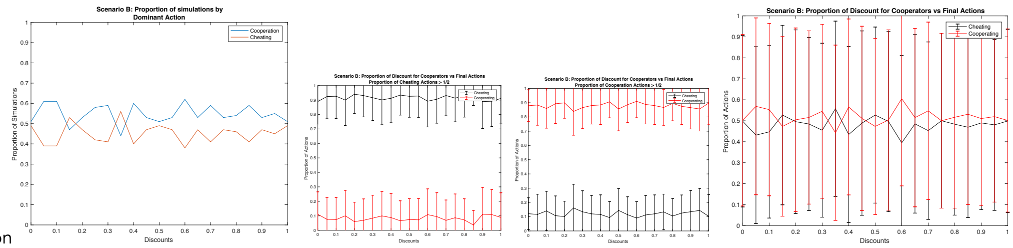
Cooperatives (ask for what you deserve), cheating (ask all the water you need to maximize production), TFT for each interactive partner see what he did at first, and the copy (reciprocity with neighbors 4)

2 actions:

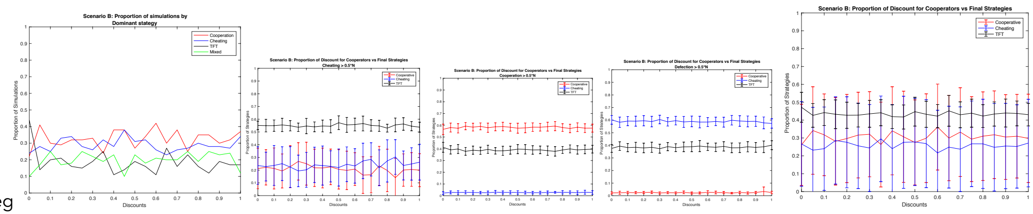
Cooperatives = lower consumption of water and off (you behave well and ask for water that is up to you)

Cheating = water consumption maximizing the payoff

SCEARIO B discount



action



strateg

SCENARIO B Discount e 4 players

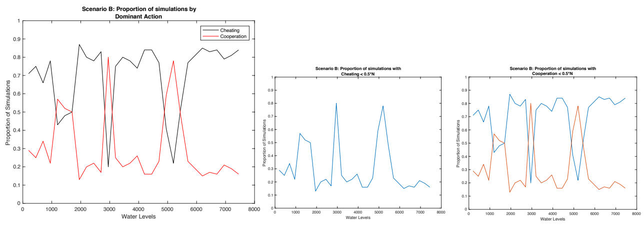
Comparing scenario A with B, we observe that there are multiple equilibrium, cheating is still dominant but cooperation is closer. The probailist choice of cooperation increase and that defeating is not anymore the secon dominant choice. Exploring the equilibrium we can see that the discoutn is not influencing as we obtain horizontal lines, but the reciprocity (TIT for TAT) is playing a role.
The number of person in the network are influencing the strategy choice, we can say that the informaiton increases and it can be used to make the choice so it does influence the choice.

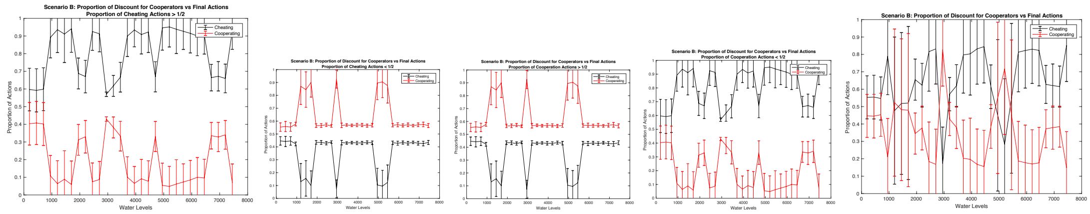
- reciprocity and information availability are influencing decision makers

1. the dicount is not influencing decision making

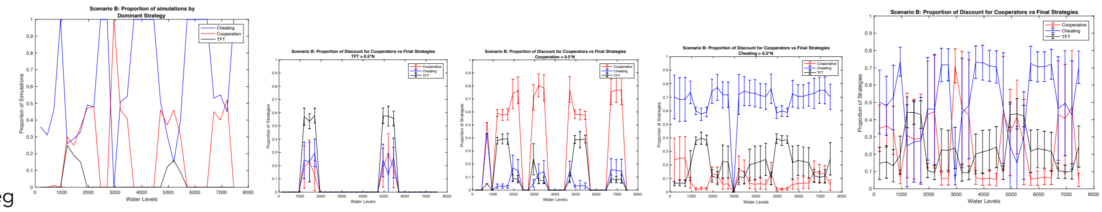
SCEARIO B water

Action





strateg



SCENARIO B Water e 4 players

Comparing scenario A with B, we observe that there are still multiple equilibrium, cheating is still dominant but cooperation is growing. In fact the probailist choice of cooperation increases. From left to right we can notice that higer level of water are favouring stable and dominat equilibrium, while from righ to left diminishig amount of water are increasing choice variability. Comparing with the same graph in secanrio A, the equilibrium are even closer. Changing amount of water, even small when water is more scarce in a scnarion wit reciprocity and the increasing of the amoun of informaiton is favouring cooperation to emerge.
The number of person in the network are influencing the strategy choice, we can say that the informaiton increases and it can be used to make the choice so it does influence the choice.

- reciprocity and information availability are influencing decision makers
- water varibaility is playing a role and scarce water availability create space for choice variability.

SCENARIO C - TFT ^ 2

3 strategies:

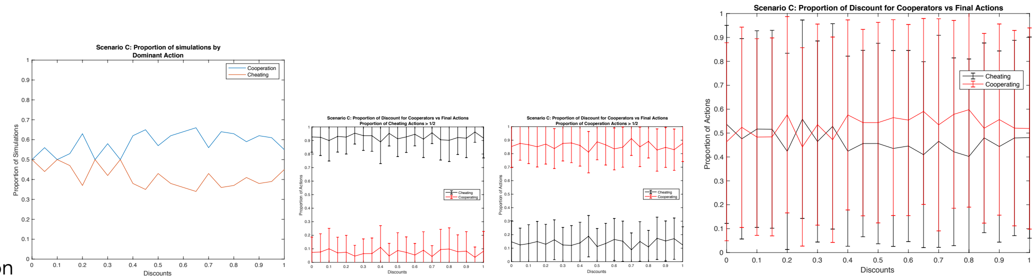
Cooperatives, Cheating, TFT (reciprocity with neighbors 8)

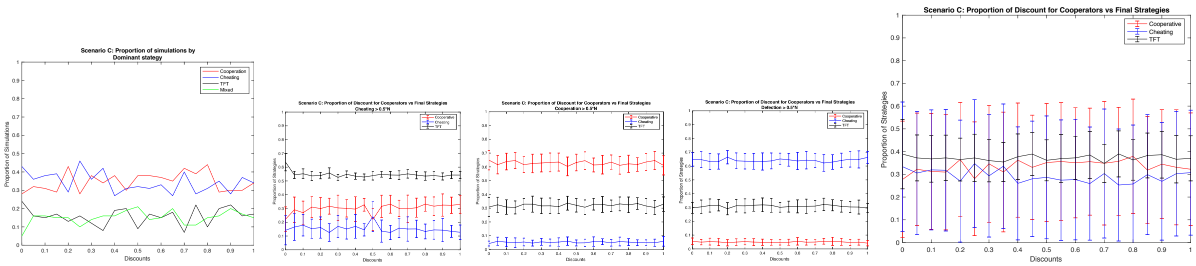
2 actions:

Cooperatives = lower consumption of water and off

Cheating = water consumption maximizing the payoff

SCEARIO C discount – 8 players

action 

strateg 

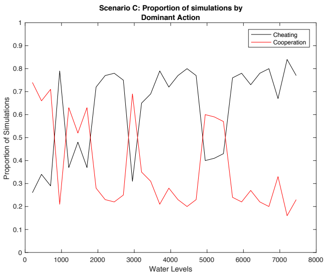
SCENARIO C Discount and 8 players

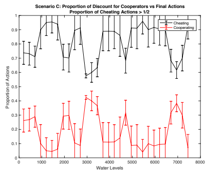
Comparing scenario B with C, we generally observe an amplification fo the phenomna observed in B. We have multiple equilibrium, and cooperation is growing. The probailist choice of cooperation increase also at the increase of the discount. Exploring the equilibrium we can see that the discount is influencing the cooperative equilibrium adn that this sum with reciprocity (TIT for TAT). The number of person in the network are influencing the strategy choice, we can say that the informaiton increases and it can be used to make the choice so it does influence the choice.

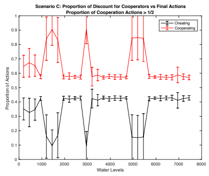
- reciprocity and information availability are influencing decision makers
- in the case when coopearation in dominat, with a growing network, the discount is starting to work
- incentive is working when we reach a certain information level, when the network is closer and the palyer keep the payoff high

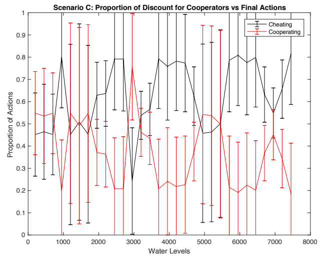
SCEARIO C water

Action

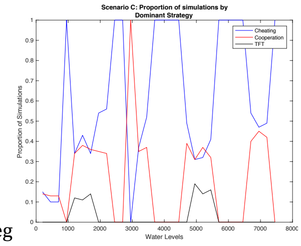


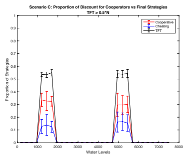


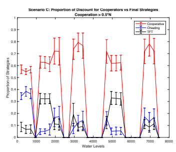


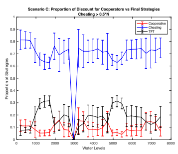


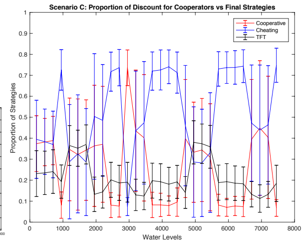
Strateg











SCENARIO C water and 8 players

Comparing scenario B with C, we generally observe an amplification fo the phenomna observed in B. We have multiple equilibrium, and cooperation is growing. The probailist choice of cooperation increase also at the increase of water level. Exploring the equilibrium we can see that the for scarce water amount the cooperation si sligthly increasin and that reciprocity (TIT for TAT) and a growing network are the factors behind this increase.
The number of person in the network are influencing the strategy choice, we can say that the informaiton increase can be used to make the choice so it does influence the choice.

- reciprocity and information availability are influencing decision makers
- in the case when coopearation in dominat, with a growing network, the cooepration is growing

information and reciprocity are helping decision maker when water is scarce