



Research

Corruption risks, management practices, and performance in water service delivery in Kenya and Ghana: an agent-based model

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ABSTRACT. Our emphasis is on the management of water service delivery (WSD) and on the institutional dynamics of the actors involved in the various water systems, therefore focusing on the interplay between human society and the environment. Water service delivery in Kenya and Ghana is of low quality and there are weak integrity mechanisms in place, which are prone to corruption. Water service delivery is also characterized by pragmatic and opportunistic management practices. We explore the extent to which corruption and management practices affect the performance of WSD by developing an exploratory agent-based model (ABM) that builds on the principal-agent theory. Based on empirical research from case studies in Kenya and Ghana, the different actors involved in WSD are modeled in terms of principals and agents that play various games reflecting different social dilemmas. Payoffs from the games are defined based on transparency, accountability, participation, and the social costs of the relationship between the principals and the agents. Decisions made by bounded-rational actors take into consideration the expected payoff but also social comparison. The results show that corruption risks and opportunistic practices reduce the performance of WSD. Furthermore, the relevance of the work is the highlighting of the use of social simulation (ABM), built on case studies, to understand these complex relationships in Kenya and Ghana.

Key Words: *corruption; management; performance; water service delivery*

INTRODUCTION: CORRUPTION AND MANAGEMENT IN WATER SERVICE DELIVERY (WSD) IN KENYA AND GHANA

Governance failures are one of the key reasons for unsustainable resources management in general, and water management in particular. Economic development often focuses on and leads to fulfilling the needs of the human population at the expense of the environment (Vörösmarty et al. 2010, Pahl-Wostl et al. 2012). Pahl-Wostl and Knieper (2014) showed that the effectiveness of formal institutions is more important than the state of economic development when explaining the failure of a governance regime. Their analyses showed that governance regimes characterized by high levels of corruption did not enhance water security, neither for humans nor the environment. Thus, understanding the reasons for and the possibilities to overcome corruption is an issue of major concern.

Ostrom (1998) defined rent-seeking as nonproductive activities that are directed toward creating opportunities for higher profits than would be obtained in an open, competitive market; e.g., the public infrastructure provider has an incentive to engage in rent-seeking by imposing high taxes on the resource users while not investing in public infrastructure. According to the rent-seeking theory, corruption has been associated with the incompetence of the state to ensure efficiency in water provision and cost recovery. It was, therefore, expected that commercialization through private sector participation (PSP) and sector reform (regulation, decentralization) would help to reduce corruption and improve the performance of water utilities (Repetto 1986).

However, Boehm (2007) suggested that the low levels of efficiency of water utilities, persistent patterns of corruption, and limited water access for the most vulnerable population show that these approaches have failed. In its turn, management practices seem

to have an important role in understanding why the performance of water service delivery (WSD) remains low in spite of the sector reform and the PSP. Auriol and Blanc (2009) analyzed the problem of corruption and the capture of public water utilities in Sub-Saharan Africa. In this seminal paper, Auriol and Blanc (2008:2) point out that “water utilities run by private-public partnerships are not optimally managed either because private managers and government are incompetent or not benevolent.”

Kenya and Ghana are Sub-Saharan African countries that began to reform the water sector in the 1990s in an attempt to improve the performance of the water supply. The change in institutions and organizations of policy and regulation, provision, and consumption levels defines a specific governance model in each country. The reform affected the different WSD levels. At the policy and regulation level, both countries developed regulatory frameworks. In terms of provision, Kenyan municipal water services were transformed into public corporations, whereas Ghana embraced PSP. Both countries developed commercialization measures to increase cost recovery. At the consumption level, participation by users was introduced by adopting customer-care strategies from providers (GII 2011, TIK 2011).

Bellaubi and Visscher (2014) assessed the quality of WSD in five case studies in Kenya and Ghana and identified low levels of coverage, high levels of rationing, and low water quality in these locations. Furthermore, Bellaubi and Visscher (2016) identified a number of corruption risks in both countries by looking at the actors involved in WSD and their multiple relationships in a complex network. These relationships were analyzed using a principal-agent framework in which the agents provide a service and the principals pay a return. Corruption risks were identified by looking at the integrity, in terms of transparency, accountability, and participation (TAP) levels, of the

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relationships between the principals and agents involved in the different WSD levels (Bellaubi and Visscher 2010) from policy and regulation to provision and consumption.

In turn, Bellaubi (2004) suggested that clarity of rules between actors in water allocation in an irrigation system is related to different types of management (water distribution), which have an effect on the performance of the system (yields). Various types of management practices have been distinguished in the literature (Batley 2004, Huppert 2005, Molle and Berkoff 2007), namely “opportunistic” (in which the provider of a service will tend to use their power to divert benefits in their own direction), and “pragmatic” (in which the provider’s actions are based on the concept of comfort margin and minimum overload). However, these definitions remain very broad and qualitative, and we suggest a more specific categorization through the following research question: how do corruption risks and management practices affect the performance of WSD governance in Kenya and Ghana? To investigate the complex relationships between management practices, corruption, and performance of WSD, an agent-based model (ABM) built on the principal-agent theory was developed and applied to Kenya and Ghana. The conceptualization of agents and their interactions builds on game theory. The different interaction situations are conceptualized as different games that reflect social dilemmas. The results of the ABM allow observation of the total payoff of the water system (performance), identifying the most successful management strategy under specific integrity conditions. Therefore, the model can be used to set up clear remedial actions and policies to increase the quality of WSD by enhancing integrity and improving management in WSD.

RESEARCH METHODOLOGY

Water systems may be considered social-ecological systems (SES; Anderies et al. 2004), composed of biophysical and social components with a physical and institutional infrastructure, which affects the way the system functions to cope with diverse external disturbances and internal problems over time. The low performance of SES constitutes a social dilemma when actors face choices in which the maximization of short-term self-interest yields important outcomes but their choice reduces the overall performance of the system (Ostrom 1998).

Models using game theory have been used in social sciences to simulate social dilemmas (Axelrod 1984, Lambsdorff 2007; J. Fábrega 2008, *unpublished manuscript*). However, game theory, which is based on rational choice theory, falls short when it comes to capturing real actors’ behaviors in various ways. Rational choice theory relies on objective probabilities for decision making, although according to Savage (1954), probabilities can also be subjective, whereas in reality, decisions are made within complex and changing environments in which objective probabilities are unobtainable (Bell 2012). People rarely have access to all the information they need to make choices. In addition, the ability to process information is usually far too limited to follow the theory’s prescriptions (Kirkeboen 2009). According to Simon’s bounded rationality concept (Simon 1955, as cited in Kirkeboen 2009), actors do not optimize but opt for satisficing choices; a behavior that results from their adaptiveness and from learning from previous decisions.

Another point is that an actor’s behavior is a function of the person and his/her environment, including other actors (Lewin 1943). Most importantly, actors do not consider only the utility derived from a specific interaction, but also positive or negative social impacts (social gain/cost) that result from their decisions (J. Fábrega 2008, *unpublished manuscript*). In game theory, the structure of the interactions between actors is restricted to being either too rigid or fully random, and none of the interaction structures properly reflect the structure of social networks.

Agent-based modeling is a modeling approach used in various disciplines and allows individual entities and their interactions to be directly represented (Gilbert 2008). This makes it an attractive approach for modeling social dilemmas (Kehagias 1994, Szilagyi 2003, Sheng et al. 2008, Szilagyi and Somogyi 2008, Power 2009), considering the role of different types of social networks (Nowak and May 1992, Hauert and Doebeli 2004, Santos and Pacheco 2005; see also http://www3.nd.edu/~netsci/TALKS/Santos_CT.pdf), and, more directly, addressing the problem of corruption (Situngkir 2003a, b, Guerrero 2009).

Although the study of corruption has been approached through laboratory (Lambsdorff and Frank 2007) and field experiments (Olken 2007), the results obtained have a high degree of abstraction and may not entirely capture the heterogeneity of an actor’s behavior and its interactions with the environment (Balacco 2011).

The ABM we describe is an exploratory learning model (Pahl-Wostl et al. 2007) that makes it possible to simulate how actors in the water system interact among themselves. The aim of the ABM is to understand the relationship of corruption risks and management practices with the performance of WSD, considering social links from a power perspective and also from the cognitive abilities of the actors. This combines adaptive (learning) and interactive (relationships with others) expectations. The ABM builds on a principal-agent representation for Kenya and Ghana WSD that results from analyzing three case studies in Kenya and two in Ghana, carried out as a part of Transparency International’s “Transparency and Integrity in Service Delivery in Africa Program” (Bellaubi and Visscher 2014). Each case study represents a specific water situation within the service area of a water provider or water utility (hence, the water system). This empirical information, both qualitative and quantitative, is used as input data for the ABM to test the conceptual model and to extract more general conclusions (Janssen and Ostrom 2006).

DESCRIPTION OF THE PRINCIPAL-AGENT REPRESENTATION IN KENYA AND GHANA

The principal-agent representation, based on Huppert (2005), makes it possible to represent actors (organizations or individuals) that are related to each other under specific governance mechanisms (rules such as contracts and regulations) and transactions (services and returns). The relationship is that an actor acting as an agent offers a service to an actor acting as a principal, and in return, the principal pays the agent. The agent can hide information from the principal, failing ex-ante to provide the service. In turn, the principal can refuse ex-post any return for the service provided. Finally, an external observer, i.e., an independent actor not directly involved in the principal-agent transaction, can verify and influence the transaction if sufficient

information is accessible to him. Bellaubi and Visscher (2010, 2016) defined different levels of integrity for each of these transactions in terms of transparency, accountability, and participation (TAP; Table 1), in which a low level TAP identifies high corruption risks. Furthermore, the variable of social cost was introduced to estimate the grade of influence (power) of an agent over the principal or the opposite.

Table 1. Integrity definitions and levels.

Integrity definition	Scoring levels (participatory scoring)
Transparency: existence of clear written rules and regulations defining relationships between actors	1 = Comprehensive written rules. 0.5 = Rules are one-sided. 0 = Rules are verbal or incomprehensible.
Accountability: application of control mechanisms for holding actors responsible for their actions based on the rules and regulations	1 = Applied control mechanisms on services and returns. 0.5 = Control mechanisms not enforced. 0 = Control mechanisms do not exist.
Participation: accessibility of information to third parties with a possibility to influence the outcome of the relationship	1 = Third party can influence the outcome. 0.5 = Third party limited access to information. 0 = No access to information.
Social cost: ties between actors influencing the outcome of the relationship	0 = The actors are autonomous/independent. 0.5 = An actor may be influenced by a peer.

In turn, different management practices can be characterized by TAP levels and power balance between principals and agents (Table 2; Bellaubi and Visscher 2010, Bellaubi 2011; F. Bellaubi and F. Boehm 2016, *unpublished manuscript*). We differentiate between two situations: (1) those situations in which power is unequally distributed (asymmetry of power) between principals and agents and presents corruption risks. Such situations are referred to as opportunistic management. In these cases an actor who holds power over a peer may misuse it to behave opportunistically because of the low TAP levels; (2) situations in which there is a power balance between principals and agents, which present corruption risks. Such situations are referred to as pragmatic management. In these cases, principals and agents behave reactively and are motivated by their own interest because there is low TAP.

Table 2. Management practices and transparency, accountability, and participation (TAP)-power characteristics.

Management definition	Characteristics
Pragmatic management: actor's behavior based on own interests	Low TAP (high corruption risk) and power balance between actors
Opportunistic management: actor's decisions based on own interest to take advantage of the peer	Low TAP (high corruption risk) and asymmetries of power between actors

To measure the performance of WSD in each of the case studies, a water service delivery approach (WSDA) was used (Bellaubi and Visscher 2014). The WSDA analyzes the quality of the service in a specific location of the service area of a water utility and, thus, refers to its performance within that location in terms of the quality of the service obtained by the users/consumers. The performance of the WSD of a water system is considered as the result of all interactions between the principals and agents measured at the user's end (Table 3).

Table 3. Water service delivery approach (WSDA) performance indicators and their levels.

Indicator definition	Scoring levels (participatory scoring)
Continuity (percentage of population in the areas that use the piped supply as their main water)	0 = < 4 h/d; 1 = 4-10 h/d; 2 = > 10 h/d
Quality (taste, colors, smell as perceived by the users)	0 = < 90%; 1 = 90-95%; 2 = > 95% of tests in compliance with the residual chlorine standards
Coverage (uninterrupted hours of supply)	0 = < 50%; 1 = 50-90%; 2 = > 90%
Affordability (users' restriction in consumption because of cost)	0 = > 10% people restrict water; 1 = 5-10%; 2 = < 5%
Quantity (litres of water consumed per household)	0 = < 20 l/c/d; 1 = 20-100 l/c/d; 2 = > 100 l/c/d

The principal-agent representation in Kenya and Ghana

The case studies in Kenya were carried out in Old Town (Mombasa), Migosi (Kisumu), and Kangemi (Nairobi). In Ghana, the case studies were carried out in Nima and Madina (Accra). The main actors involved at policy making and regulation, provision, and consumption WSD levels in each country are listed in Table 4.

The principal-agent representations in Kenya and Ghana (Figs. 1 and 2) show the principals' and agents' relationships and their governance mechanisms. In the case of Kenya, the governance mechanisms follow a public governance model, whereas in Ghana, the governance mechanisms relate to PSP. The legend describes the service provided by the agent and the return of the principal, the TAP, and social cost scores of the relationship with a brief explanation and the identified corruption risks and management practices based on data from GII (2011), TI Kenya (2011), Bellaubi and Visscher (2014), and Bellaubi (*personal observation*).

At the policy and regulatory levels

In Kenya, the regulator, Water Services Regulatory Board (WASREB), acts as an agent and the government Ministry of Water and Irrigation (MWI) acts as a principal. The relationship is characterized by low TAP (regulatory opportunism risk) and the unequal distribution of power between the principals and agents resulting in an opportunistic management in which politicians have the opportunity to abuse some regulatory powers for their own purposes. A similar situation happens in Ghana with

Table 4. Main actors involved in water service delivery (WSD) in Kenya and their roles.

Levels	Actors and their roles in Kenya	Actors and their roles in Ghana
Policy and regulation	Ministry of Water and Irrigation (MWI): overall coordination of the water sector, setting policies and legislations, and sourcing funds. Water Services Regulatory Board (WASREB): approving the operators (WSP) that are selected and regulating tariffs.	Ministry of Housing, Works and Water (MHWW): overall coordination of the water sector, setting policies and legislations, and sourcing funds. Public Utility Regulatory Commission (PURC): examining and approving tariffs, monitoring and enforcing standards of performance, receiving and investigating complaints, and settling disputes between consumers and providers.
Provision	Water Services Providers (WSPs): operating and maintaining the systems and providing water and sanitation services. Municipality owner of the WSPs. Water service providers are corporate public utilities.	Ghana Water Limited Company (GWLC): legal owner of the system and responsible for the provision, distribution, and management of urban water supply, as well as responsible for its rehabilitation and expansion. Aqua Vitens Rand Limited (AVRL): private operator responsible for production, distribution, billing, revenue collection, and setting the tariffs.
Consumption	Users active paying recipients of water.	Users passive paying recipients of water.

the regulator, Public Utilities Regulatory Commission (PURC) acting as an agent and the government Ministry of Housing, Works and Water (MHWW) as a principal.

At the provision level

In Kenya, municipalities act as agents and water companies, Water and Sanitation Program (WSPs), act as principals. The low TAP (political opportunism risk) and the fact that municipalities exert their power to influence the decisions of the companies for their own benefit indicate an opportunistic management.

In Ghana, the water operator, Aqua Vitens Rand Ltd. (AVRL), is the agent and the water agency, Ghana Water Company Ltd. (GWLC), is the principal. The low TAP between agent and principal points to a state capture risk in which AVRL may take advantage of GWLC, shaping the design rules of the service management contract in its favor. However, the fact that there is a balance of power between both actors makes it difficult for AVRL to profit from its situation resulting in a pragmatic management.

At the consumption level

In Kenya and Ghana, the relationship between water companies (agents) and users (principals) is characterized by low TAP and balance of power between the agent and the principal resulting in pragmatic management. Moral hazard and free-riding were identified as corruption risks, meaning the possibility of encountering two different situations: users may free-ride the service, or water companies may take advantage of the service provided by the utilities.

Regarding the WSD, performance of the water systems in Kenya and Ghana was calculated as the average of the differently scored indicators per case study. In Kenya, the total performance in the various case study locations ranged from 20% to 26.6%. In Ghana, the total performance ranged from 13.3% to 20% (Table 5).

DESCRIPTION OF THE AGENT-BASED MODEL (ABM)

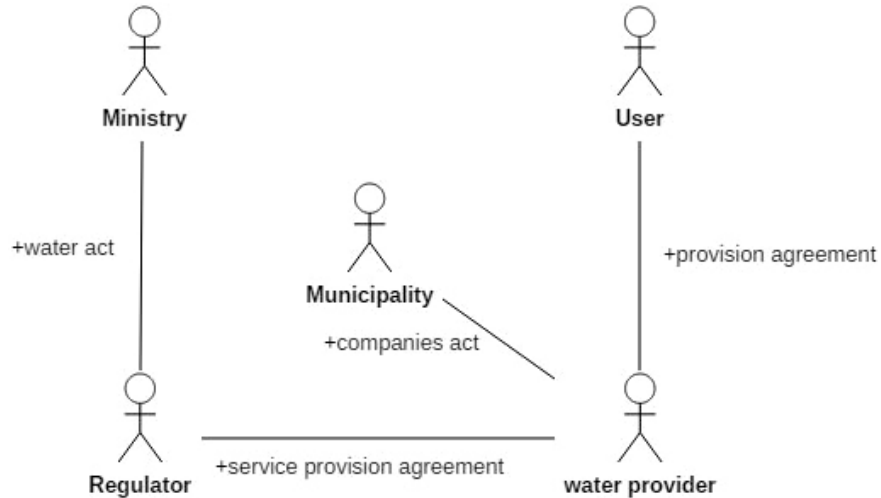
The ABM is described according to the overview, design concepts, and details protocol (ODD) in Bellaubi et al. (2014) and was implemented in Netlogo version 4.1.3 (Wilensky 1999). The ABM builds on a principal-agent representation in Kenya and Ghana

(Figs. 1 and 2), in which actors playing as agents or principals relate to each other in terms of services and returns, respectively. The transaction sets up a game in which cooperation means following the rule of law, whereas defecting is equivalent to breaking the rule of law. Actors can play in multiple games simultaneously and can be a principal in one game and an agent in another game at the same time. The empirical observation of the actors in the case studies suggests that decisions to cooperate or defect consider both the utility maximization derived from a specific interaction, and the positive or negative social impacts (social gains/costs) as a result of their decisions (J. Fábrega 2008, *unpublished manuscript*). According to Janssen (2008), experimental research has shown that people value not only material payoff but also nonmaterial consequences, such as an improvement or deterioration in social relationships.

The performance of WSD refers to the payoff obtained by an actor as the result of a service or a return for this service. The TAP and social cost/gain values of the relationships determine the payoff table from which the actors get their payoff according to their decisions to cooperate or defect. The total performance of WSD is measured as the sum of the different payoffs obtained by all the actors involved as the result of the transactions among all of them.

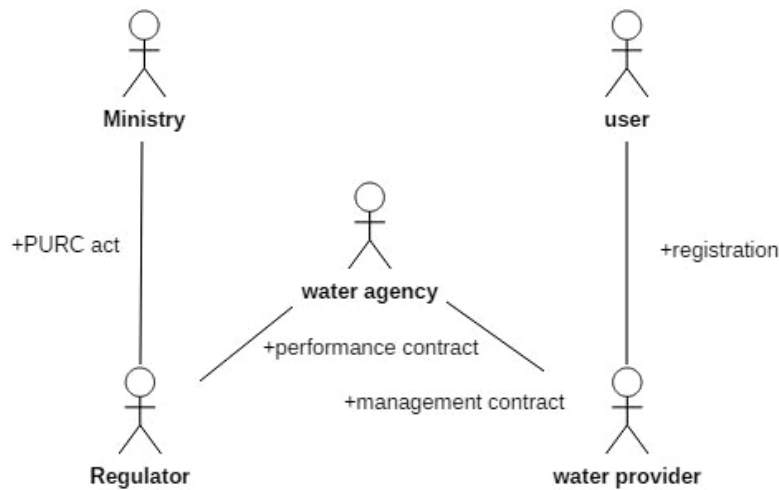
The model time step is one month and it runs for 12 months, simulating the cycle of water service provision through one whole year. The games are played in each time step sequentially with the agent acting first and the principal second. The sequence gives to the agent a “first-to-choose” power over the principal. This situation is counterbalanced by the principal being aware of the agent’s decision. This sequence reproduces the principal-agent representation in which the agent offers services and the principal gives a return. The agent reiterates his previous decision if this has been good enough when comparing his payoff with the other actors linked to him (neighbors). If this is not the case, he tries to improve by taking into account expectations of the principal’s behavior to maximize his utility. The principal is affected by, and knows about, the previous decision of the agent, and the principal is, thus, easily able to maximize based on the previous decision of the agent. Afterwards, the agent adapts his expectations of the

Fig. 1. Main actors involved in water service delivery (WSD) in Kenya.



relationship water provider (agent) – user (principal)	
service agent	Water provision
return principal	Monthly payment of the water bills
transparency	0.5, it is not clear what happens if water provider does not provide water
accountability	0.5, water provider does not compensate users if no service
participation	1, complaints followed up by regulator
social cost	0, autonomy between both
corruption risk	Moral hazard/ free-riding
management	Pragmatic
relationship regulator (agent) – water provider (principal)	
service agent	Supervision of performance standards
return principal	Levy (percentage of billing)
transparency	1, service provision agreement is clear in its understanding
accountability	0.5, it is not clear how regulator reinforces its role
participation	0.5, information is accessible to third parties
social cost	0, autonomy between both
corruption risk	Regulatory opportunism
management	Opportunistic
relationship regulator (agent) – ministry (principal)	
service agent	Regulation in water service provision
return principal	Financial resources to implement ministry policies
transparency	1, Water Act is clear in its understanding
accountability	0.5, regulator funding depends on ministry
participation	0.5, information is accessible to third parties
social cost	0.5, regulator members appointed by ministry
corruption risk	Regulatory opportunism
management	Opportunistic
relationship municipality (agent) – water provider (principal)	
service agent	Lease of assets through Water Service Boards
return principal	Dividends plus lease of the assets
transparency	0.5, original contract not available
accountability	0.5, corporate guidelines not applied
participation	1, ministry can influence decisions
social cost	0.5, municipality influences on the water provider Board of Directors
corruption risk	Political opportunism
management	Opportunistic

Fig. 2. Main actors involved in water service delivery (WSD) in Ghana. Note: GWCL = Ghana Water Company Ltd.



relationship water operator (agent) – user (principal)	
service agent	Water provision
return principal	Monthly payment of the water bills
transparency	0, no contract but a registration form
accountability	0.5, water operator does not compensate users if no provide with service
participation	0.5, regulator does not follow up complaints
social cost	0, autonomy between both
corruption risk	Moral hazard/ free-riding
management	Pragmatic
relationship regulator (agent) – water agency (principal)	
service agent	Supervision of performance and tariff setting
return principal	No return
transparency	0.5, it is not clear how tariffs are approved
accountability	0.5, it is not clear how regulator reinforces its role
participation	0, the information is not accessible to third parties
social cost	0.5, the water agency influences on regulator
corruption risk	Regulatory opportunism
management	Opportunistic
relationship regulator (agent) – ministry (principal)	
service agent	Regulation in water service provision
return principal	Financial resources to implement ministry policies
transparency	1, PURC Act is clear in its understanding
accountability	0.5, regulator funding depends on ministry
participation	0, the information is not accessible to third parties
social cost	0.5, the regulator members appointed by ministry
corruption risk	Regulatory opportunism
management	Opportunistic
relationship water operator (agent) – water agency (principal)	
service agent	Operations, maintenance, and reporting
return principal	No return by GWCL
transparency	0.5, original contract not available
accountability	0.5, sanctions are not applied
participation	0.5, regulator follows up performance of water operator
social cost	0, autonomy between both
corruption risk	State capture
management	Pragmatic

Table 5. Performance score in Kenya case study locations following a water service delivery approach (WSDA).

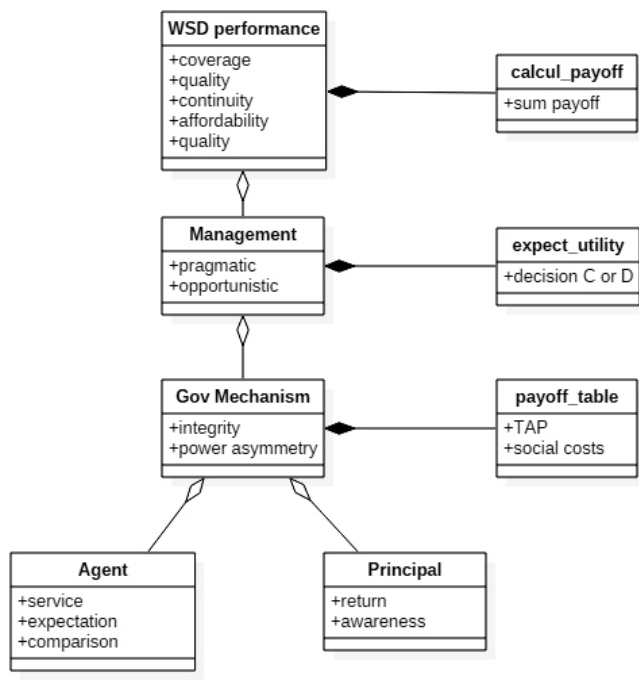
Performance indicator (max. value 3)	Old Town (Kenya) Mombasa Water Supply and Sanitation Company (MOWASCO)	Migosi (Kenya) Kisumu Water And Sewerage Company (KIWASCO)	Kangemi (Kenya) Nairobi City Water and Sewerage Company (NCWSC)	Madina (Ghana) Aqua Vitens Rand Limited (AVRL)	Nima (Ghana) Aqua Vitens Rand Limited (AVRL)
Continuity	0	1	0	0	0
Quality	0	2	1	2	2
Coverage	0	0	0	0	1
Affordability	2	0	2	0	0
Quantity	1	1	0	0	0
Total score	3	4	3	2	3
% of the total performance of the system	20.0%	26.6%	20.0%	13.3%	20.0%

The highest performance is achieved when the total score per case study is 15.

principal's behavior. The various agents' and principals' choices per round constitute the strategy of the game. These strategies may vary over time and they can be cooperation-cooperation (Cc), defection-defection (Dd), cooperation-defection (Cd), or defection-cooperation (Dc).

The ABM is calibrated against the performance of the WSD of the water system found in the case studies. Finally, the ABM's resulting strategies for each game and the associated payoffs (representing WSD performance) are compared with different management practices defined by the principal-agent representation of the case studies.

Fig. 3. Class diagram. Note: WSD = water service delivery. TAP = transparency, accountability, participation.



Payoff table

Each game is defined by a payoff table in which R is the reward for mutual cooperation, T is the temptation to defect, S is the “sucker’s payoff,” and P is the payoff for mutual defection. The values in the payoff table are derived from the transparency, accountability, participation (TAP) and social cost/gain scores of the transactions between a principal and an agent.

R is the service offered by the agent or the return that the principal pays to the agent to obtain the service when both cooperate. The optimal service/return can be arbitrarily valued as 1, i.e., R = 1. It is assumed that if both act according to the law, this has no effect on social relationships.

T is the temptation of the agent to provide only a suboptimal service while receiving an optimal return, or the temptation of the principal to receive an optimal service but to provide only a suboptimal return. T can hence arguably be higher than R. This depends, however, on the accountability of the transaction, which reflects punishment through the control mechanisms in place. To reflect on these considerations, the following settings were made: $T = 1.5 - \text{accountability}$, where $\text{accountability} \in [1, 0]$ and, therefore, $T \in [1.5, 0.5]$.

S is the sucker’s payoff that results in being cheated when offering an optimal service or an optimal return but receiving only a suboptimal service or suboptimal return. S increases with the level of participation of the transaction and decreases with the social cost involved of not reciprocating. Participation thus includes the observation of the transaction through third parties (e.g., NGOs, the general public, regulators) and the resulting incentive to act according to the law, even if cheated by one’s peers. This incentive is modeled as the benefit received by the cheated, if he/she decides to cooperate. In turn, the social costs reflect the social consequences for an individual of his/her personal decision and becomes relevant in cases in which the agent or the principal has strong social ties with the peer, e.g., a bribe that is offered and the rejection of which causes a disturbance in the receiver’s social relationships in terms of social costs. The rationale is that actors may suffer from the so-called “bureaucrat’s dilemma:” “sometimes [bureaucrats] need to bend rules to remain a participant on [sic] network of reciprocity (even at his own risk and without immediate retribution)” (J. Fábrega 2008:28 unpublished manuscript). Actors are, thus, members of networks

and their decisions are influenced by their role as a member of the network. The social cost quantifies the power of the agent over the principal or the opposite in terms of the level of ties between the agent and principal; when the ties between peer actors are high then the social costs are also high, assuming that asymmetries of power between peer actors increases the social costs (the actors are bounded to positively reciprocate because of the social ties). It is assumed that direct social ties weigh more than participation. The following was set: $S = (\text{participation} / C) - \text{social cost}$, where participation $\in [0,1]$, social costs $\in [0, 0.5]$, and consequently, $S \in [-0.5, 0.5]$. C is a variable allowing the calibration of the model. Social costs are equivalent to social gain: when social costs are low, then $(\text{participation} / C) - \text{social costs} > \text{social gains}$, therefore $S > P$.

P is the suboptimal service or return of the principal and the agent, respectively, when both defect and can be considered almost nil. It is considered that when both the agent and principal break the rule of law, there is a corrupt deal (Lambsdorff 2007) involving social gain as a result of the social ties of reciprocity between the agent and the principal. Social gains are considered to be equivalent to the social costs introduced above, such that $P \in [0, 0.5]$.

According to the principals' and actors' choices to cooperate or defect, the payoff values obtained are $R, T, S,$ or P for the agent and $r, t, p,$ or s for the principal (Table 6).

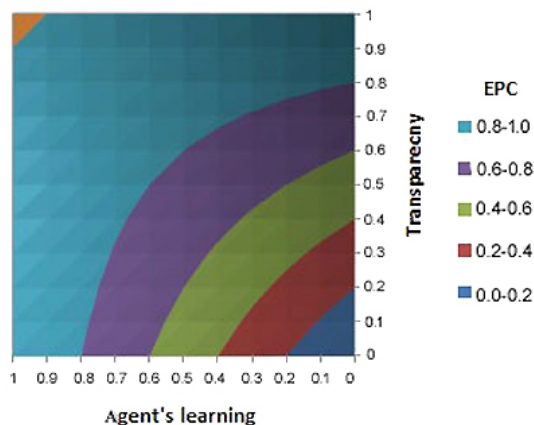
Table 6. Payoff table.

		Principal's choice	
		Cooperation	Defection
Agent's choice	Cooperation	R, r	S, t
	Defection	T, s	P, p

The decision-making process

The processes executed for each round of the games between agents and principals are: (1) the agent's decision, (2) the principal's decision, (3) getting a payoff, and (4) updating expectation. A sequence diagram is given in Figure 4.

Fig. 4. Relation between agent's learning and transparency. Note: EPC = the agent's expectation that the principal will cooperate.



(1) In the agent's decision, the agent reiterates his previous decision if, on average, he/she has been better off than his/her neighbors (other actors linked to him/her). The assumption is that the agent does not have the full information about the consequences of acting differently and, therefore, evaluates his previous decision as "good enough" as long as he is at least as well off as his peers in the network. If this is not the case, he tries to improve his position through taking a deliberate decision based on the maximization of the expected utility (EU) considering the expectation about the principal's behavior (EPC), as follows:

$$EU_{\text{agent}}(C) = EPC * R + (1 - EPC) * S$$

$$EU_{\text{agent}}(D) = EPC * T + (1 - EPC) * P$$

when,

$$EU_{\text{agent}}(C) > EU_{\text{agent}}(D), \text{ then agent Cooperate}$$

$$EU_{\text{agent}}(C) \leq EU_{\text{agent}}(D), \text{ then agent Defect}$$

(2) In the principal's decision, the principal maximizes his payoff (EU) based on the knowledge of the agent's prior decision to cooperate or defect.

if at t , $\text{agent_decision} = \text{cooperate}$

$$\text{then } EU_{\text{principal}}(c) = r \text{ and } EU_{\text{principal}}(d) = s$$

if at t , $\text{agent_decision} = \text{defect}$

$$\text{then, } EU_{\text{principal}}(c) = t \text{ and } EU_{\text{principal}}(d) = p$$

when,

$$EU_{\text{principal}}(c) > EU_{\text{principal}}(d), \text{ then principal cooperate}$$

$$EU_{\text{principal}}(c) \leq EU_{\text{principal}}(d), \text{ then principal defect}$$

(3) While obtaining a payoff, payoff values are assigned to the agent and the principal according to the values of the payoff table, taking into consideration both decisions.

(4) Finally in updating expectation, the agent's expectation of the principal's behavior is updated based on the principal's decision. The agent's expectation that the principal will cooperate (EPC) or defect $(1 - EPC)$ is influenced by the learning capacity of the agents that weights off the current experience with the expectations that have been built up in previous games.

If the principal decides to cooperate, then the expectation that the principal will act in a similar way in future games is increased.

if at t , $\text{principal_decision} = \text{cooperate}$

$$\text{then, } EPC(t + 1) = EPC(t) + (1 - EPC(t)) * Lc$$

with Lc being the learning rate assigned to each agent, where $0 < Lc < 1$.

If the principal decides to defect, then the expectation that the principal will cooperate in future time steps decreases.

if at t , $\text{principal_decision} = \text{defect}$

$$\text{then, } EPC(t + 1) = (1 - Lc) * EPC(t)$$

The initial value of EPC is equal to the transparency of the principal-agent transaction.

RESULTS OF THE AGENT-BASED MODEL (ABM)

Understanding a single principal-agent model

To calibrate the model, it is necessary to determine the variables affecting the outcomes (strategies and payoffs) in the ABM. This is done through the simulation of an agent and a principal playing a single game (single principal-agent model).

The analysis focuses on understanding the importance of the various variables in the ABM so that the actors can reach the equilibrium (“stable” strategy on time), considering a strategy as set up by the agent’s and principal’s decisions. The resulting strategy depends on the values of accountability, participation, and social costs that define R, T, S, and P, the agents’ and principals’ initial decisions and the agent’s expectations of the principal’s behavior. The latter is a function of the learning capacity of the agent and the transparency of the relationship between the principal and the agent. The multiplicity of all the possible games played by the principals and agents can be abstracted into three social dilemmas known from game theory (http://www3.nd.edu/~netsci/TALKS/Santos_CT.pdf): the snow drift (SD) game ($R > T > S > P$), the prisoner’s dilemma (PD; $T > R > P > S$), and the stag hunt (SH) game ($R > T > P > S$).

The single principal-agent model shows that a game (social dilemma) can develop several strategies through the year depending on the initial decisions of the agent and the principal. When the agent’s initial decision is such that he is at least as well off as the principal (neighbor), and the principal maximizes his payoff with his initial decision, equilibrium is attained in the first round. In some cases, the principal does not maximize his payoff with his initial decision and then equilibrium is attained in the second round. When the payoff for the agent is smaller than the payoff for the principal (neighbor), the agent’s expectations of the principal’s decision plays a role in defining the subsequent decisions and the equilibrium of the game. The agent’s expectations of the principal’s decision take into account the agent’s learning and the previous expectation of the principal’s decision. The higher the agent’s learning, the more the initial decision of the principal is taken into account. Whereas the lower the agent’s learning, the transparency between the agent and the principal influences the agent’s expectations of the principal’s decision (Fig. 4).

Figures 5, 6, and 7 show the evolution of strategies for each social-dilemma, when an agent’s initial decision payoff is smaller than the principal’s initial decision payoff and for different values of the agent’s learning.

Figure 8 displays different payoff tables for a single principal-agent model, in which each payoff table represents a social dilemma. Each payoff table shows the possible equilibriums according to game theory (marked with *), the ABM resulting equilibrium strategies (marked in bold) and the path (in arrows) in how ABM resulting strategies are reached when the agent’s and principal’s initial decisions differ from these resulting strategies.

Subsequently, the dynamics of strategies over time only become important if the initial setting is not the resulting equilibrium of the specific game. In fact, agents’ and principals’ initial decisions have a delaying role in reaching equilibrium within the year represented by 12 runs, as stated by game theory for the different social dilemmas. As a result, the overall performance over the year

in question differs from the one predicted by game theory for the different social dilemmas.

Agent-based model (ABM) calibration

The calibration of the model is done comparing the WSD’s performance given by the ABM with the WSD performance measured from the case studies. The WSD’s performance given by the ABM is the sum of the payoffs of all the actors’ relationships. In the case studies, the WSD performance of the water system results from all the actors’ interactions involved at the different WSD levels: policy and regulation, provision, and consumption and this is measured at the user’s end (Table 5). Because the WSD’s performance of the case studies is not measured in absolute but in relative terms to benchmarking, a percentage of the performance is given. This percentage is then applied to the resulting payoffs of the ABM and, thus, both performance and payoffs can be compared.

The input variables for the calibration of the ABM in Kenya and Ghana are:

1. The structure of the social network, i.e., who plays which game with whom and in what role (what the games are, who the agent is, and who the principal is).
2. Transparency, accountability, participation, and social costs of the transactions between principals and an agents, defined in the principal-agent representation (Figs. 1 and 2). These values define the payoff table and, thus, the games (social dilemmas) played by the agents and principals.
3. The variable C setting the relationship between participation and the social cost in the payoff table is the parameter for the calibration of the ABM.
4. Multiple combinations of the initial actors’ decisions play a role in delaying the resulting strategy and, therefore, the total payoff, but do not change the resulting strategy of the game played by the agents and principals. The actors’ initial decisions are applied to two situations: the initial decisions of all the actors are set in cooperation, and the initial decisions of all the actors are set in defection. This enables a comparison of how payoff (performance) changes under situations of initial cooperation between actors.
5. Empirical evidence from the case studies confirms that agents learn from the previous principals’ decisions.

The NetLogo BehaviourSpace tool produces the total payoff outputs for all the C values. Figures 9 and 10 list the C variables in relation to the total payoff values with the more similar values, in comparison to the relative WSD performance, as measured in the case studies in Kenya and Ghana (Table 5). The WSD performance average in Kenya was taken at 23.3%, which equals to a total payoff of 61 for the ABM when all the actors’ initial decisions are defection and 67.0 when all the actors’ decisions are cooperation. In Ghana, the average WSD performance was set at 16.6%, which equals a payoff of 56.9 and 61.9 when all the actors’ initial decisions are defection or cooperation, respectively.

The resulting C values of the calibration in Kenya (1.6) and in Ghana (1.8) show that in both cases, social ties weigh more than participation. In addition, the results show that when the actors’ initial decisions are cooperation, the payoff is higher than when they choose defection.

Figures 5 to 8.

Fig. 5. Evolution of the strategies in the stag hunt game.

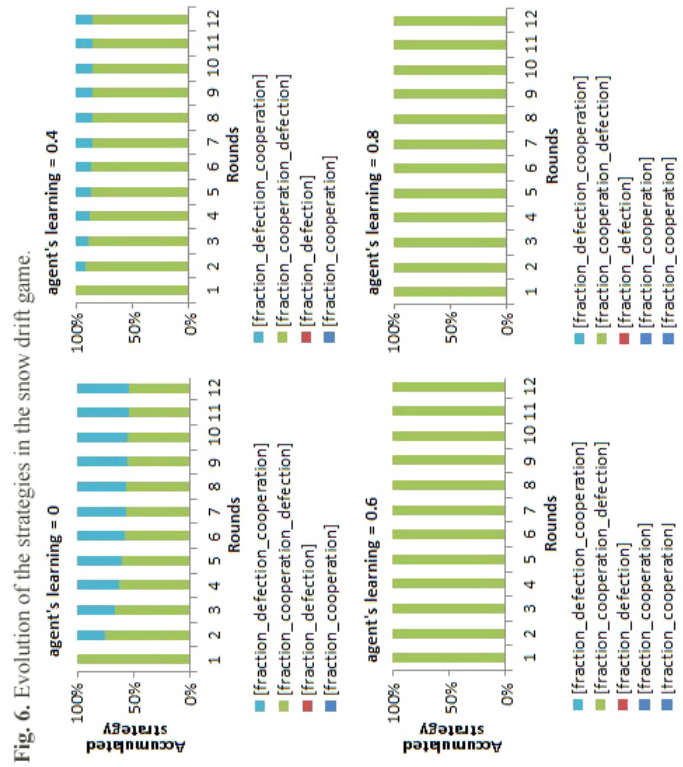
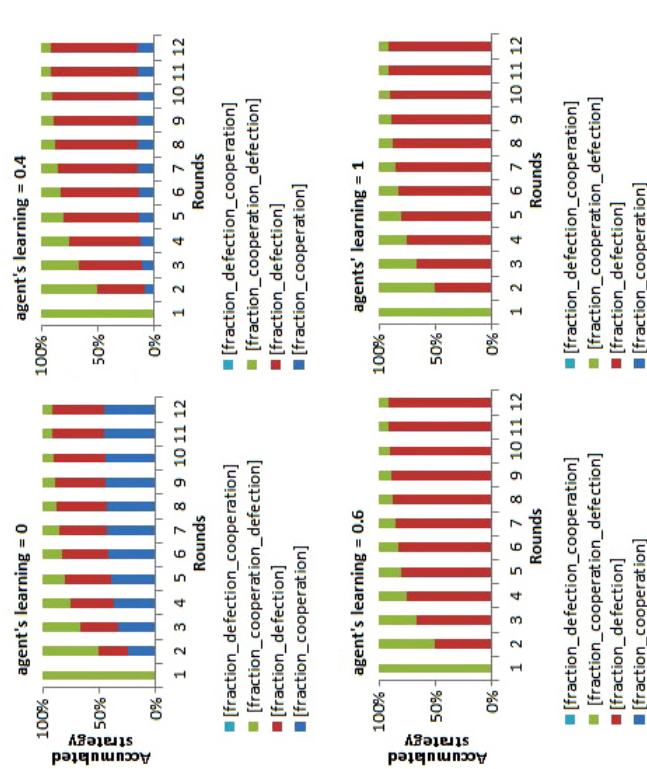


Fig. 6. Evolution of the strategies in the prisoner's dilemma game.

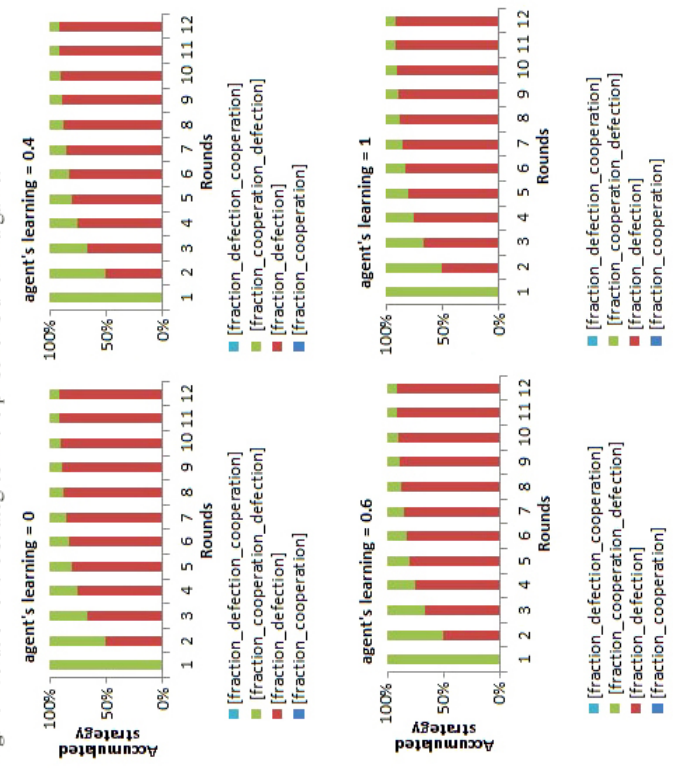


Fig. 7. Evolution of strategies for different social dilemmas. Note: SH = stag hunt, SD = snow drift, PD = prisoner's dilemma.

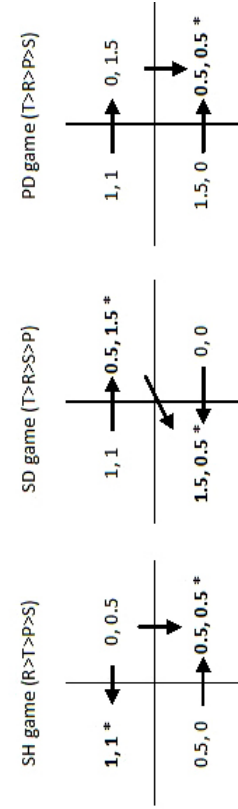


Table 7. Corruption risks, management practices, resulting strategies, and performance in Kenya and Ghana.

Agent-principal at water service delivery level		Management practices		Corruption risks		Agent-based model strategy		Social dilemma		Payoff (performance)	
Kenya	Ghana	Kenya	Ghana	Kenya	Ghana	Kenya	Ghana	Kenya	Ghana	Kenya	Ghana
Policy and regulation											
Regulator - government	Regulator - government	Opportunistic	Opportunistic	Regulatory opportunism	Regulatory opportunism	Dd	Dd	PD	PD	+	+
Regulator - water company	Regulator - water agency	Opportunistic	Opportunistic	Regulatory opportunism	Regulatory opportunism	Cd	Dd	SD	PD	+++	+
Provision											
Municipalities - water company	Water operator - water agency	Opportunistic	Pragmatic	Political opportunism	State capture	Dd	Dc	PD	SD	++	++
Consumption											
Water company - users	Water operator - users	Pragmatic	Pragmatic	Moral hazard/ free-riding	Moral hazard/ free-riding	Cd	Cd	SD	SD	++++	++

+ represents the relative payoff of the relationship principal-agent regarding the other relationships' payoffs

From the calibration of the single principal-agent model, it can be inferred that the same results in terms of ABM resulting strategies are obtained for all combinations of the agents' and principals' initial decisions. However, the payoffs vary from the maximum when all agents' and principals' initial decisions are cooperation to the minimum when agents' and principals' initial decisions are defection.

Fig. 9. C and payoff values in agent-based modeling (ABM) in Kenya.

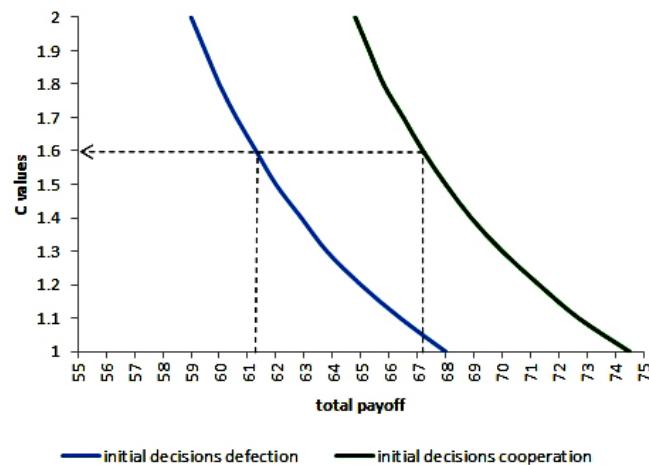
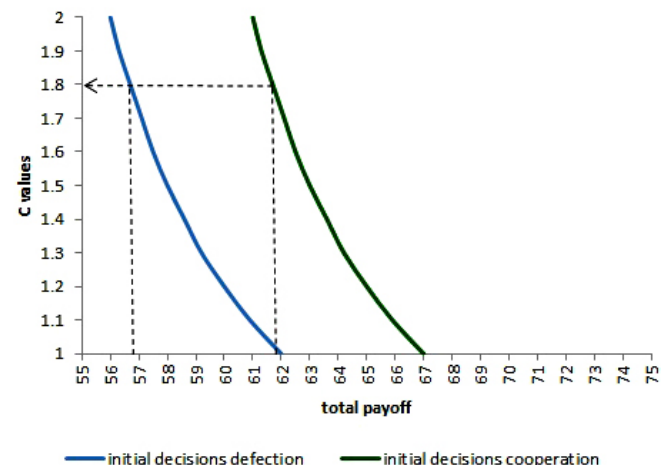


Fig. 10. C and payoff values in agent-based modeling (ABM) in Ghana.



Results of the agent-based model (ABM) in Kenya and Ghana

We examine the resulting strategies from the different games played between agents and principals in the Kenyan and Ghanaian ABM in relation to the observed corruption risks and management practices at the different WSD levels from the respective country principal-agent representation. Resulting strategies in each game are compared with the equilibriums of social dilemmas derived from game theory (Table 7). The following points are observed.

Dd strategies resulting from the ABM may explain corruption risks, opportunistic management, and low performance. Dd

strategies emerge in two cases: first, when the temptation for the agent to defect is high ($T \geq R$), the principal will defect if the social gain is high ($P > S$), resulting in a Dd strategy as in the prisoner's dilemma, i.e., the principal cannot refuse a corrupt "contract" offered by the agent because strong social ties of positive reciprocity exist. The higher the social gain, the higher is the payoff of the agent and the principal. Second, Dd strategies are also reproduced when the temptation of the agent to defect is low ($R > T$) and the social gain is high ($P > S$). In this case, Dd strategies occur as in the stag hunt dilemma. However, this second situation is not found in the model.

Corruption risks and pragmatic management are characterized by Cd/Dc strategies. Cd/Dc strategies appear when the agent and the principal play a snow drift dilemma. Empirical findings from the case studies at consumption level suggest a successive shift in Cd/Dc strategies in the ABM to reproduce moral hazard and free-riding situations. However, the sequential structure of the model with the agent “moving” first does not allow this situation to be reflected. When the agent’s temptation to defect is high ($T > R$), the principal will cooperate if the social cost is low and participation is high ($S > P$), resulting in Dc strategies as in the snow drift dilemma, i.e., the principal can afford to refuse the agent’s decision. In other words, the principal will cooperate if the payoff through participation is high and the social cost is low. The symmetric situation (Cd strategies) arises if the agent initially chooses to cooperate and, consequently, the principal defects. The equilibrium reflects negative reciprocity in both cases.

In terms of performance and according to Bellaubi and Boehm (2016, *unpublished manuscript*), wins and losses of the actors involved in a water system play a role in the WSD performance. Therefore, resulting payoffs mimicking wins and losses of principals and agents through different games for different WSD levels can be related to the ABM strategies and further with the identified management practices derived from the case studies. Through a comparative analysis that establishes a possible relationship between two variables (x , y) in different given situations (A, B), it is possible to observe how different payoffs relate to certain management practices in Kenya and Ghana. The results of the ABM depicted in Table 7 show that payoffs associated with the prisoner’s dilemma are, in both countries, lower than payoffs resulting from the snow drift dilemma.

OVERALL DISCUSSIONS AND CONCLUSIONS

The ABM presented is a deterministic explanatory learning model that aims to explain how corruption risks and management practices affect WSD’s performances in Kenya and Ghana, considering the role of learning and social networks.

The ABM draws on the principal-agent theory. In the model, coupled actors play different simultaneous games to reflect the various social dilemmas involved in WSD in Kenya and Ghana. This distinguishes the model from similar ones of competition for natural resources in which several actors play the same game (Janssen 2008; see also http://www3.nd.edu/~netsci/TALKS/Santos_CT.pdf). Despite the maximization behavior of the agents, their bounded nature is taken into consideration by the ABM. There are two elements that go beyond a simple (repeated) utility maximizing game: (1) the social costs of not reciprocating, which changes the payoff structure of the (simple) game; and (2) learning about the success of different strategies whereby strategies are considered good if the payoff is at least as high as the neighbor’s average.

The relation between management practices and corruption risks established by the ABM may explain the performance that emerges from social-dilemma strategies. In other words, the strategies in the ABM may explain the principal-agent behavior (cooperation or defection) under specific corruption risks and management practice situations and the resulting performance. Furthermore, the ABM allows these management practices and the associated corruption risks to be related to the characteristics of the transaction between the agent and the principal, namely

transparency, accountability, participation and social costs, the agent’s learning, and initial decision values.

In broader terms, the ABM relates the integrity of rules among water actors that constitute the governance aspect of their relationships with the behavioral norms grounded in asymmetries of power, which shape the water political arena (hydro-politics). Management practices can be seen as the interface of policies and politics, with the resulting WSD performance being a characteristic of the governability (Kooiman et al. 2008) of the water system.

In terms of results, the ABM model shows that regulatory and political opportunism corruption risks may occur under opportunistic management. The ABM strategies associated with opportunistic management are in line with the prisoner’s dilemma equilibrium, which point to strong social ties between principals and agents. That is the case of regulatory bodies and government in Kenya and Ghana and between water companies and municipalities in Kenya, as shown by the principal-agent representation based on empirical findings of the case studies.

Under pragmatic management, moral hazard, free-riding, and state capture may occur. In this case, ABM resulting strategies match with equilibriums of the snow drift game, involving low social cost and gain between the principals and the agents. This situation appears between the water companies/water operator and the users in Kenya and Ghana, and between the water operator and the water agency in Ghana.

The results also show that the payoffs resulting from the prisoner’s dilemma are lower than those from the snow drift dilemma. This suggests that opportunistic management and corruption risk involving strong social ties between relevant actors of the water system have a higher negative impact on the WSD performance.

These results can be put into perspective regarding the work done by Ostrom (1998), stating that when reciprocity rules are in place creating a linkage between players and collective action, players tend to collaborate receiving more benefits than if they all do not cooperate. According to our research and in line with J. Fábrega (2008, *unpublished manuscript*), reciprocity can have an adverse effect when specific players want to keep a dominant role as members of a network because of their social links, as shown when opportunist management occurs.

Certainly, our research shows that certain types of management practices associated with corruption risks play a role by negatively affecting the performance of WSD in Kenya and Ghana. It has also shown that case studies and social modeling can be combined to help visualize the situation of water systems, thus providing opportunities to improve performance and enhance integrity. Nevertheless, one of the limitations of the ABM is the simplification of the actors involved in the different WSD levels. This does not allow the social network role and the learning in actors’ behaviors to be fully evaluated. In other words, what happens in one game does not necessarily influence what happens in another game. The simulations show that this learning has little influence on the results. It was observed in several cases that equilibrium is reached after a number of interactions are played between principals and agents. The question remains as to whether a higher number of actors with an increasing number of neighbor relationships would have an impact on how equilibrium strategies are developed.

Responses to this article can be read online at:
<http://www.ecologyandsociety.org/issues/responses.php/9205>

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