Towards an improved understanding of free-riding in collective irrigation systems: proposition of a basic system dynamics model

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Abstract

A basic system dynamics model for collective irrigation management is proposed, which is aimed at improving the understanding of dynamic processes in collective irrigation systems. In particular, the problem of free-riding on water in irrigation systems is addressed. A feedback system is introduced, which builds on the concept of a critical mass and integrates a number of influence factors that have been identified to play a key role for farmers' motivation for co-operation in irrigation. The base run corresponds to the relatively frequent situation of deteriorating irrigation infrastructure and unsuccessful co-operation. Yet, by varying initial conditions and parameters, the model also describes successful co-operation. Lines of further development are suggested, including a generalisation of the proposed model for collective natural resource management.

Key words

Collective irrigation management, common property resource management, critical mass, threshold model, sustainable resource management.

1 Introduction

The study of collective irrigation systems is relevant for several reasons: first, water is a primary natural resource, and as such, a fundamental condition for increasing agricultural productivity in rural areas to improve food security, and to generate additional income streams for farmers through the cultivation of cash crops (Molden 2007, Norton 2004). Second, farmer-managed, collective systems are widespread (Molden 2007) and have been found to operate often very efficiently (Vermillion and Sagardoy 1999). Nonetheless they face specific problems, such as frequent deterioration of irrigation infrastructure, insufficient contributions by the users, free riding in water abstraction, inequity between upstream and downstream users causing tensions, and possibly violent conflicts.

Collective irrigation management and common property resource management in general have been the focus of broad research in the past decades. Major influence factors in farmer co-operation have been examined (Baland and Platteau 1996; Facon 2002; Gardner et al 1990; Lam 1998; McKean 1998; Ostrom 1990; Tang 1992; Ul Hassan 2004; Vermillion and Sagardoy 1999; Wade 1988, 1988a) and design principles for successful collective resource management have been identified (Agrawal 2001; Meinzen-Dick and Knox 1999; Ostrom 1992, 1992a, 1999; Wade 1988). Yet, as pointed out by Agrawal (2001) there is a need for an integrated systemic approach with regard to collective resource management. This paper is aimed at suggesting a system dynamics model for collective irrigation management, which can be considered an example of such an integrated systemic approach to collective resource management.

Moreover, general theories for collective action, bearing on the concept of a critical mass, have been proposed by Schelling (1978) and Granovetter (1978), and have further been developed by Marwell and Oliver (1993) and Oliver and Marwell (2001). It has been argued, that they may be appropriate to describe processes of natural resource management in resource poor countries (Baland and Platteau 1996; Runge 1992). However, up to the point, critical mass models have not been developed for collective irrigation management. It is attempted to propose a system dynamics model, which builds on the concept of a critical mass, as to capture the dynamics of collective action, and integrates a number of findings related to collective irrigation management.

This paper proposes a basic system dynamics model, as to address the problem of free-riding in a collective irrigation system. Thus, the problems of unequal access to water and of illegal water abstraction upstream are neglected here.[1] The proposed model builds on theory of collective action and collective irrigation management, as well as on two case studies in Kyrgyzstan and Kenya. The study has been conducted within the framework of the Swiss National Centre of Competence in Research (NCCR) North–South, which aims at contributing to the mitigation of syndromes of global change by international research co-operation.[2]

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[1] For the discussion of an extended model including illegal water abstraction upstream, refer to Gallati (2008).

[2] For further information about the NCCR North-South, see http://www.north-south.ch.

2 Background

This section starts with an elaboration on major influence factors in farmer co-operation in collective irrigation systems. In particular, those influence factors are discussed that have been included in the proposed basic model. Second, a framework for common property resource management is presented. Third, the critical mass and threshold models for collective action proposed by Schelling (1978) and Granovetter (1978) are introduced. These models provide a general dynamic theory of collective action, which the proposed feedback system for collective irrigation management builds on.

2.1 Collective irrigation management

Collective irrigation systems have been studied extensively and major influence factors in farmer co-operation have been examined (Baland and Platteau 1996; Facon 2002; Gardner et al 1990; Lam 1998; McKean 1998; Ostrom 1990; Tang 1992; Ul Hassan 2004; Vermillion and Sagardoy 1999; Wade 1988, 1988a). These influence factors include i) resource-related aspects, such as water availability, water scarcity and reliability, ii) socio-economic aspects, such as dependence on resource, levels of poverty, diversification, and the capacity to pay, iii) group characteristics, such as group size, homogeneity or heterogeneity of assets and interests, and population growth, and iv) institutional aspects, such as equitable access, conflicts, sanctions, enforcement, allocation rules, and pricing and financing.

Out of these, the basic model proposed here includes the following influence factors:

Water availability

Water availability and reliability of water supply are primary conditions for farmers to contribute their labour to maintain the canals, to pay water fees, and to follow regulations for water abstraction. Norton (2004, 234) states that ‘the reliability factor… is so important that its absence even can affect farmer’s willingness to dedicate their labour to operation and maintenance tasks’.

On the other hand, it has also been argued that water scarcity is a major motivation for farmers to contribute to collective irrigation (Ostrom 1990, Wade 1988). However, the effect of water scarcity on collective action is ambiguous. Wade stresses the key relationship between the scarcity of a vital resource and collective action, noting that ‘where survival is at stake, the rational individual will exercise restraint at some point’. (Wade 1988, 205).’ On the other hand, Baland and Platteau make the point that under *continuous* pressure of crisis conditions, collective action may be prevented from arising (Baland and Platteau 1996, 298).

As a consequence, water availability and its effect on agricultural production on the one hand, and water scarcity on the other, are taken into consideration as two separate influence factors.

Capacity to contribute

Capacity to contribute is often discussed in the context of dependence on water and users' time horizons with regard to the resource. It is argued that the higher the dependence on irrigation water, the more likely are substantial expenditures of the farmers to operate and to maintain the system (Tang 1992, 21). With regard to users' time horizons it is stated that the value of future income through the flows from a common property resource may be discounted by two groups, very poor and better-off households: on the one hand the level of wealth of the poor may be so low that they are not able to participate in collective action and thus are not willing to undertake conservation measures, even though such actions would increase further permanent income. On the other hand, better-off households with access to outside economic opportunities also tend to overexploit the resource as they anticipate a shift to alternative occupation (Baland and Platteau 1999, 774-775).

As the model proposed here assumes homogenous households, capacity to contribute is taken into consideration in a less elaborate way. From interviews in the case study areas it is concluded that farmers are willing and capable to pay the required water charges, if these charges do not exceed a certain percentage of the agricultural revenues, which they are able to derive from the irrigated area.

Allocation rules

Equitable access to a collectively managed resource plays a major role for users to co-operate in these activities. A variety of water allocation rules are in use (Tang 1992, 28-31, Schlager 2005, 40-41). Rules are different with regard to supply-based or demand-based systems. In supply-based systems equity is understood as a water discharge, which is proportionate to a certain parameter, usually the extent of the command areas (Ul Hassan et al 2004, 5). As a consequence, a reduction in water supply due to a deterioration of irrigation infrastructure affects all users in proportion to their irrigated area.

There is wide agreement that commonly agreed sanctioning mechanisms have to be in place in order to make the commons work (Agrawal 2001, Baland and Platteau 1996, Ostrom 1999, Wade 1988). All these authors integrate (graduated) sanctions into their enumeration of conditions for successful collective action. In this regard, excludability of free-riding individuals plays a major role as a form of an effective sanction.

The model proposed here refers to a supply-based allocation system. Excludability is taken into consideration as an exogenous parameter, describing the degree to which a non-co-operator can be excluded from receiving water. As such, this is the main form of sanctions, which has been considered in the model.

Pricing and financing

Pricing systems applied in irrigation systems comprise three types: fixed amount per farm, proportional charge based on area or volume, and combinations of fixed and proportional charge (Bos and Wolters 1990, Norton 2004, Vermillion and Sagardoy 1999). Currently a tendency towards proportional pricing on a volumetric basis can be observed (Norton 2004). Area pricing, in spite of its obvious disadvantage with regard to efficient water use, is still widely applied, because it is simple to administer and assures the supplier adequate revenues (FAO 1997). Authors agree widely that operation and management costs should be covered fully by water charges.

In this model area pricing is applied. Total required maintenance has to be covered by water charges, yet with a maximum, revenue dependent upper limit per area.

Payoff

In addition to these influence factors a payoff variable has been introduced, which is derived from the agricultural revenues generated from irrigated areas and the contributions for water. In particular, payoff for contributing and non-contributing users is compared and expressed by a variable termed payoff ratio. Due to the excludability parameter, contributing users receive more water than not contributing users. Yet, they have to take into consideration the water charges to be paid.

2.2 Common property resource management framework

A common property resource problem, following Gardner et al (1990, 336-337) and Ostrom (1990), is constituted by four conditions, which are typically fulfilled in farmer-managed irrigation systems.

- Resource unit subtractability
- Multiple appropriators
- Suboptimal outcomes
- Constitutionally feasible alternatives.

Irrigation systems, in addition to these four conditions, are characterised by an asymmetric access to the resource by upstream and downstream users.

Common property resource problems are further classified as provision problems, related to creating or maintaining a resource stock, and appropriation problems, related to the allocation of the yield that can be derived from the resource. In provision problems, attention is focused on the stock aspect of the common property resource, while in appropriation problems it is focused on the flow aspect of the common property resource (Gardner et al. 1990, 340; Ostrom 1990).

The model proposed here investigates possible dynamic patterns in collective irrigation, provided a given institutional setting characterised by three elements: supply-based water allocation, (limited) excludability and water pricing rules. It relates to resource provision as well as to resource allocation, and as a consequence, to the yield derived from irrigation.

2.3 Critical mass and threshold models for collective action

Several authors have argued that common property resource management problems requiring co-ordinated action, are best described by models involving a critical mass or a threshold (Axelrod 1981, Baland and Platteau 1996, Runge 1992). Here, the fundamentals of these concepts will be outlined, following the ideas of Granovetter (1978) and Schelling (1978), who both suggested threshold and critical mass models for collective action. Schelling's and Granovetter's models for collective action have led to numerous further investigations in sociology, economy, and political science (Oliver 1993, Oliver and Marwell 2001).

The threshold model proposed by Granovetter (1978) starts from preferences of the actors and presumes, 'that the decision be one where the costs and benefits to the actor of making one or the other choice depend in part on how many others make which choice (Granovetter 1978, 1422)'. Heterogeneity of preferences and interdependence of decisions over time are a central component of the model. As a consequence, distribution of thresholds matters and may decide as to whether collective action will be successful or not.

The critical mass model proposed by Schelling (1978) refers in addition to the distinction between unconditional co-operators, conditional co-operators (those who co-operate if enough others do), and unconditional non-co-operators. Schelling emphasises that [this model] '…applies perfectly well to a situation in which some fraction of the population will engage in the activity independently of how many do, and some other fraction will not, independently of how many do (Schelling 1978, 97)'.

The model proposed here builds on Schelling's model of a critical mass and Granovetter's threshold model as to describe the dynamics in collective irrigation, and integrates a number of influence factors for co-operation.

3 Proposition of a fundamental feedback structure

3.1 Rationale

This section offers a feedback system for a dynamic analysis of collective irrigation management, referring to Schelling's model of a critical mass and Granovetter's threshold model. It builds on three elements: the three categories of co-operation suggested by Schelling (1978), an S-shaped cumulative threshold distribution for conditional co-operators, and the feedback of the performance of the irrigation system on farmers' choice for co-operation.

The principal dynamics of this system is determined by the distribution curve for conditional co-operators and the categories for co-operation, as is demonstrated in figure 1. This figure shows the percentage of indicated co-operators, opting for co-operation in future, given the percentage of current co-operators. The intersections of this curve with the diagonal line (x=y) denote the fixed points in the system. Points A and C are stable fixed points, whereas B is an unstable fixed point or tipping point. Line segments below the diagonal line (x=y) indicate situations where fewer users intend to co-operate in future than currently do. Their number will decrease until point A or C is attained.

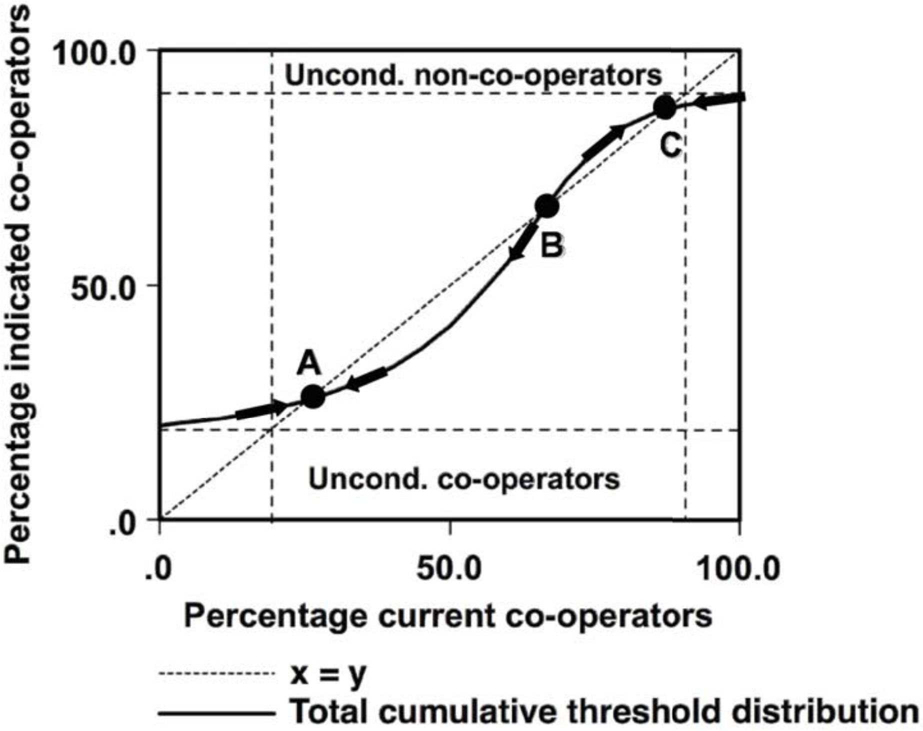

Figure 1: Total cumulative threshold distribution indicating the percentage of indicated co-operators. Unconditional co-operators co-operate regardless of what others do, whereas unconditional non-co-operators never co-operate. As a consequence, the focus is on the middle category, which are the conditional co-operators. A and C denote stable fixed points, whereas B denotes an unstable fixed point (tipping point).

The basic assumption in the proposed feedback structure is that the cumulative threshold distribution is in some way a function of the performance of the irrigation system (figure 2). If, for a given percentage X of current co-operators, this performance is perceived as satisfactory or beneficial, the thresholds to enter co-operation will be lowered, and more users will opt for co-operation in future (P´).

Yet, instead of referring to a manifold of distribution curves in function of the perceived performance of the irrigation system, a slightly different perspective is adopted in the proposed model. It is argued that it is equivalent to refer to a virtual (“modified”) percentage of current co-operators, which is increased, if performance is perceived as good

(X′). This rationale is applied, as to capture the feedback of the performance of the irrigation system, and as such the joint results of current co-operation, on farmers' choice for co-operation.

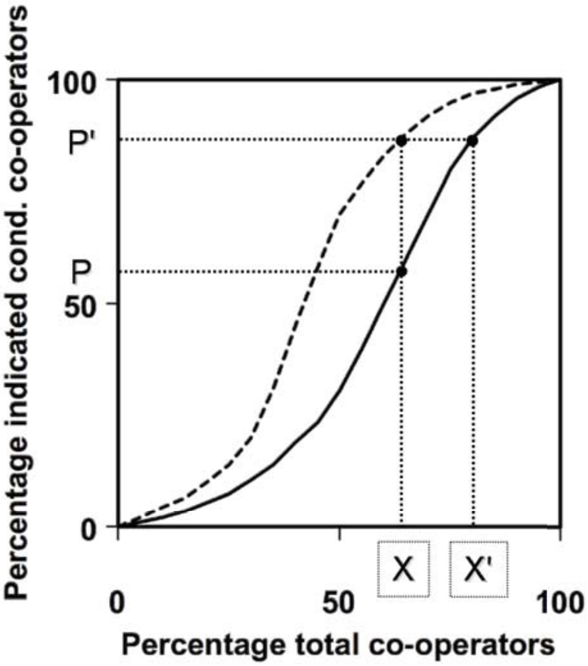

Figure 2: Feedback of performance of the irrigation system on willingness of conditional co-operators to co-operate in future. For a given percentage X of current co-operators, more conditional co-operators P′ will opt for co-operation, if performance of the irrigation system is increased. This is equivalent ***as if*** *more co-operators X′ were currently co-operating.*

In this model, which is focused on the problem of free-riding on water in collective irrigation systems, co-operation is understood as full payment of the required water charges, while non-co-operation denotes only partial payment. As such non-co-operation is equivalent to free-riding on water.

3.2 Feedback structure

This rationale is translated into a system dynamics feedback structure (figure 3). The number of indicated co-operators is a function of the categories of co-operation, the threshold distribution function, the number of current co-operators, and the performance of the irrigation system. This, however, depends on the number of co-operators, which in turn provides a basic feedback loop.

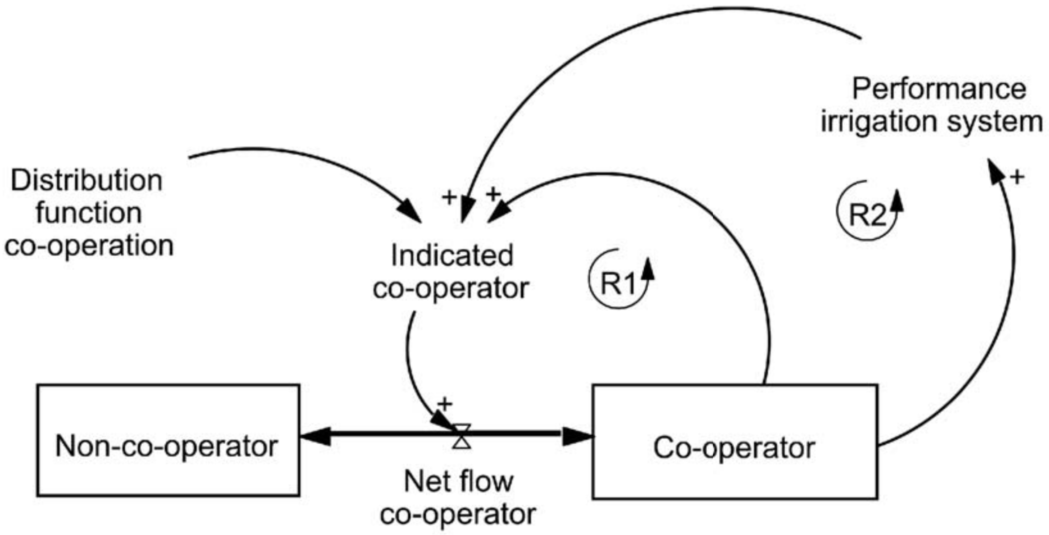

Figure 3: Structure of a critical mass model for collective irrigation management. The number of co-operating users is calculated, depending on the number of total current co-operators, the distribution function for co-operation, and the performance of the irrigation system.

Although this model would generate the expected bi-stable behaviour with a lower and an upper equilibrium, the underlying causal structure is not consistent with scientific evidence on the principal influence factors in collective irrigation management, as has been elaborated on above. As a result, the feedback structure is further developed, as to represent the influence factors for co-operation in more detail (figure 4).

This model is different from the previous in several aspects: first, performance of the irrigation system is understood as current condition of irrigation infrastructure, affecting total water supply, and in turn, water supply per household. Second, the effect of water supply per household on co-operation is differentiated, taking into consideration water scarcity, agricultural production, payoff ratio, and capacity to contribute. Third, the model structure has been subdivided into four modules, referring to co-operation, resource provision, resource allocation, and production.

Current condition of irrigation infrastructure depends on the number of co-operators and on contribution per household, which in turn is determined by required maintenance, the number of co-operators and non-co-operators, as well as of the capacity to contribute. Water supply per household is derived from total water supply and from the influence of the excludability parameter, which denotes the degree to which free-riders can be prevented from receiving water. Hence, water supply per household for co-operating and non-co-operating users are different, and as a consequence, water scarcity, agricultural production, payoff, and capacity to contribute.[3] The effects of water scarcity, agricultural production, and payoff ratio on farmers' choice for co-operation are provided by non-linear multiplier functions, which are combined into a variable termed 'co-

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[3] This differentiation, however, is not included in figure 4, as to keep the figure more transparent.

operation multiplier'. Agricultural production, finally, affects farmers' capacity to contribute.

This is considered a fundamental feedback structure for the dynamic analysis of the free-riding problem in collective irrigation, which embodies seven feedback loops. These are referred to as:

- R1: Assurance loop
- B1: Water scarcity loop
- R2: Agricultural production loop
- R3, R4: Free-riding loop
- R5: Capacity to contribute loop
- B2: Maintenance loop.

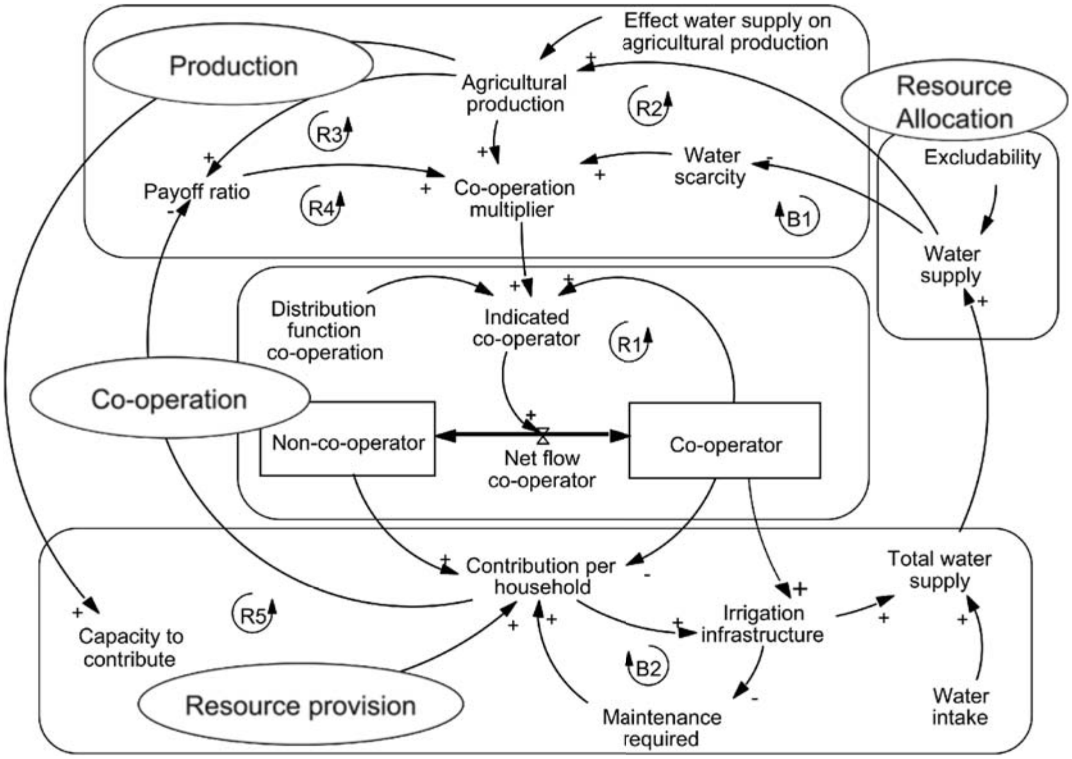

Figure 4: Fundamental feedback structure of the basic model for collective irrigation management. Variables in italic refer to exogenous parameters.

Assurance loop (R1) denotes the reinforcing feedback mechanism embodied in the critical mass model. Water scarcity loop (B1) refers to the observation that co-operation may increase in times of water scarcity. Conversely, agricultural production loop (R2) takes account of the stimulating effect of sufficient water supply on agricultural production, and in turn, on co-operation. The free-riding loops (R3, R4) relate to the effect of the payoff ratios on co-operation. Capacity to contribute loop (R5) involves the influence of water supply and agricultural production on capacity to contribute. Maintenance loop (B2), finally, derives required maintenance from the current condition of irrigation infrastructure.

It is not aimed here at presenting model equations and parameter values in detail. Yet, as a reference for the following model analysis, the non-linear multiplier functions describing the effect of the three influence factors on farmers' motivation for co-operation, are explained, and displayed in figures 5 and 6.

These three fundamental multipliers pertain to water scarcity, payoff ratio, and agricultural production. Critical water supply multiplier reflects the fact that farmers' motivation for co-operation is increased if water is scarce, and water supply is below a certain critical value. The effect of critical water supply on co-operation is given by a nonlinear graphical function (figure 5, right chart). Payoff ratio denotes the relative payoff of non-co-operators and co-operators. Co-operation is increased, if co-operator's payoff exceeds non-co-operator's payoff. The effect of payoff ratio on co-operation is provided by a graphical function, which is assumed to be partly linear (figure 5, left chart).

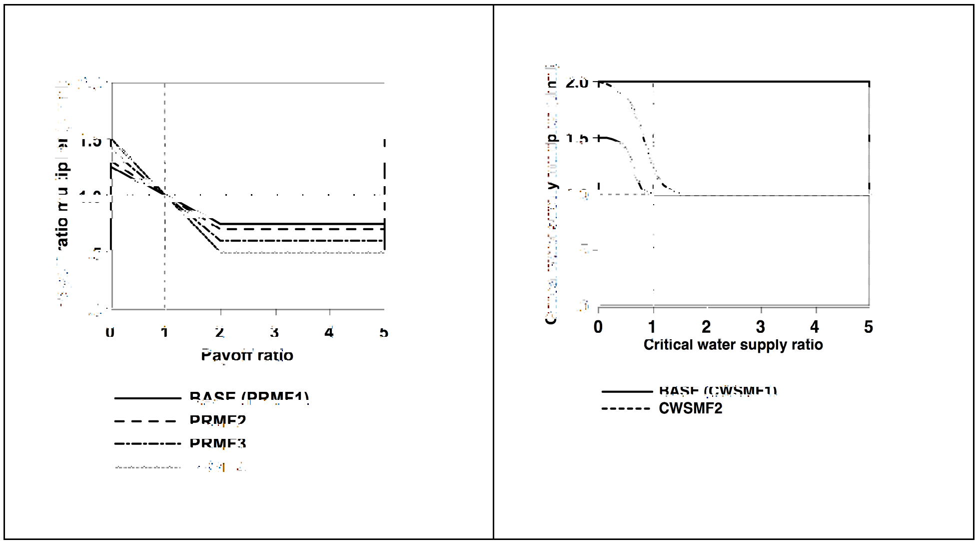

Figure 5: *Graphical functions for perceived payoff ratio multiplier (left) and critical water supply ratio multiplier (right). Payoff ratio denotes the relative payoff of non-co-operating and co-operating households. BASE refers to the graphical functions used in the base run.*

Critical agricultural revenue multiplier states on the one hand, that co-operation is only possible, if agricultural revenues are sufficient. On the other hand, it also indicates, that farmers' willingness to pay for water is increased, if water supply is plentiful. Thus, three 'regimes' are distinguished: a 'bad' situation, where agricultural revenues are insufficient and as a consequence, willingness to pay for water is limited; a 'normal' situation, where these revenues exceed a critical threshold, but are not considered good enough, as to increase farmers' motivation for co-operation; and finally a 'good' situation, where high returns encourage farmers to pay for water (figure 6).

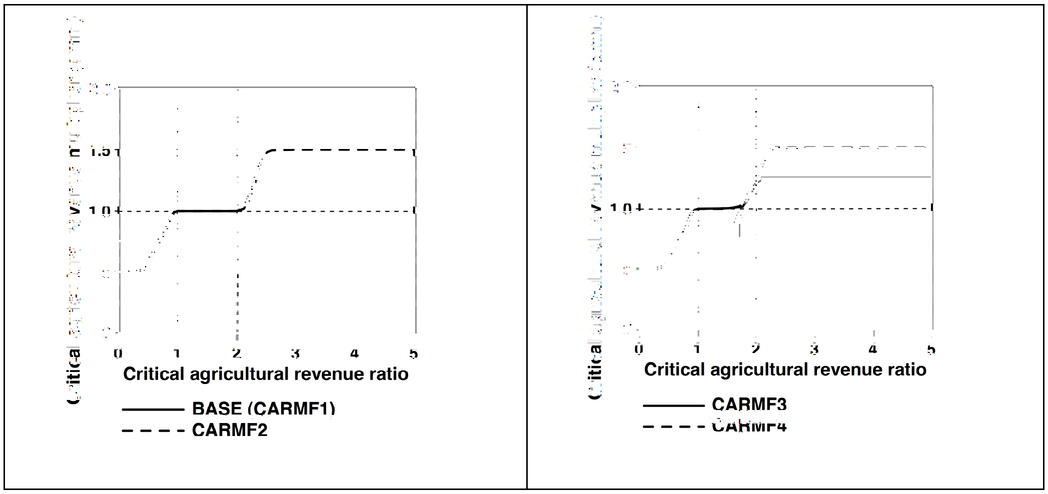

Figure 6: Graphical functions for critical agricultural revenue ratio multiplier. Critical agricultural ratio multiplier involves four different graphical functions. On the right, the 'good' regime starts at a lower critical agricultural revenue ratio (arrow). BASE denotes the graphical functions used in the base run.

4 Model analysis

The model analysis presented in this paper includes the discussion of the base run, as well as a sensitivity analysis regarding the influence of the graphical multiplier functions on model results. The base run represents the relatively frequent situation, where irrigation infrastructure is declining, and co-operation attains the lower equilibrium, although irrigation infrastructure has initially been in good condition. Yet, by varying parameters and initial conditions, transitions towards the upper equilibrium can also be induced, representing cases of successful co-operation. However, the focus of the sensitivity analysis presented here will be on the study of the graphical functions.[4]

4.1 Base run

As it has been mentioned above, the base run represents the relatively frequent situation, where irrigation infrastructure is declining, and co-operation remains on a modest level. For the base run, 50 percent of initially co-operating households are assumed.[5] Figure 7 shows the deterioration of irrigation infrastructure, which is due to an increasing gap between required and effected maintenance. Effected maintenance is decreasing for two reasons: a decline in the number of co-operators, and second, a decrease of the contribution per household (see figure 4). The latter is a result of the 'capacity to contribute' loop, which says that capacity to contribute depends on agricultural production, which in turn depends on the condition of irrigation infrastructure. Required maintenance is increasing, on the other hand, due to the continuing deterioration of irrigation infrastruc-

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[4] For a thorough discussion of a variation of parameters and initial values, refer to Gallati (2008).

[5] Author's interviews in Kyrgyzstan in 2005 indicate that this is a reasonable order of magnitude.

ture. As a consequence, the gap between required and effected maintenance is widening, and irrigation infrastructure is deteriorating.

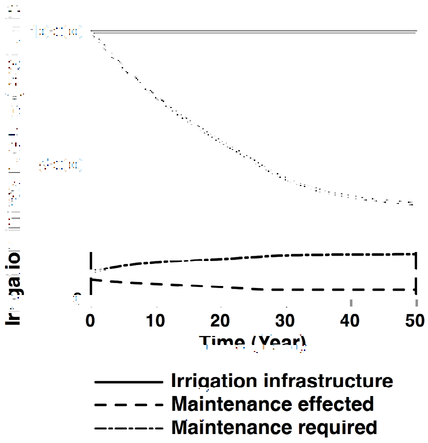

Figure 7: *Basic critical mass model for collective irrigation (base run results): irrigation infrastructure is declining due to an increasing gap between required and effected maintenance.*

As irrigation infrastructure, water supply and agricultural production are intimately connected, agricultural production and revenues per household are also decreasing (figure 8). After 25 years, average agricultural revenue per household falls below a critical value, which is assumed to be 50 cost units per household per year in the base run. This causes co-operation to decrease, as it will be explained below.

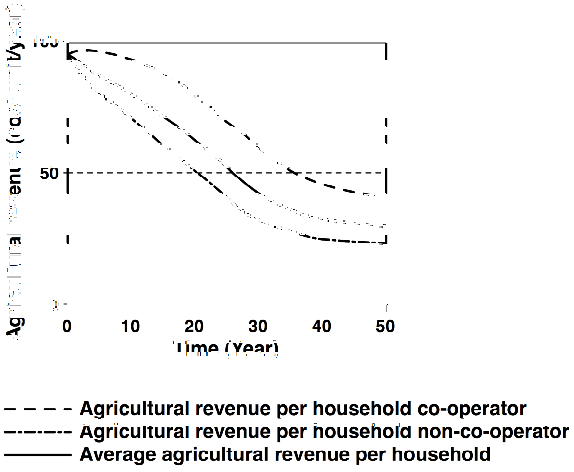

Figure 8: *Basic critical mass model for collective irrigation (base run results): average agricultural revenues per household falls below a critical threshold (50 cost unit per household per year) due to deteriorating infrastructure. Due to excludability parameter, agricultural revenue per household of a co-operator exceeds agricultural revenue of a non-co-operator.*

In addition, figure 8 demonstrates that agricultural revenues per household of co-operators exceed the corresponding values of non-co-operators. This is due to the excludability parameter, which ensures that more water is allocated to co-operators than to non-co-operators. Yet, it is the average agricultural revenue per household, which is taken into account in the multiplier function describing the effect of agricultural production on co-operation. As it will be shown below, this multiplier plays a paramount role in the model, as it strongly affects co-operation.

Co-operation is determined by the number of current co-operators, as well as by the effect of the three multipliers related to water supply, payoff ratio, and agricultural revenues.[6] This corresponds to the four feedback loops in figure 4, which are assurance loop, water scarcity loop, free-riding loop, and agricultural production loop. Hence, it is illustrative to consider the patterns of these multipliers, as to understand the behaviour of the proposed feedback structure. Figure 9 displays their values, together with those of co-operation multiplier, which provides the combined effect of the three corresponding feedback loops on co-operation.[7]

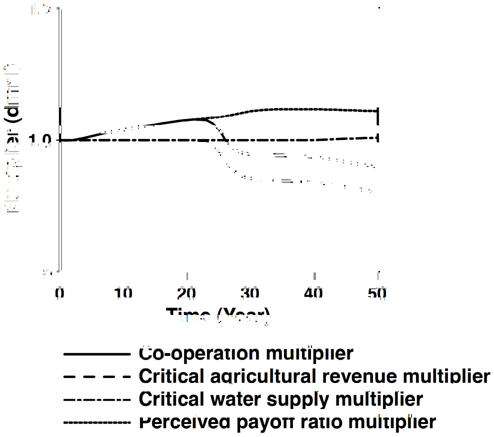

Figure 9: *Basic critical mass model for collective irrigation (base run results): values of multipliers affecting co—operation, with an overall increasing effect in the beginning, and an overall decreasing effect after 25 years.*

In the beginning, water supply is in the 'neutral' range, neither affecting critical agricultural revenue multiplier, nor critical water supply multiplier. After a certain time, when average agricultural revenue per household falls below a critical value (see figure 8), critical agricultural revenue multiplier begins to drop. However, water supply remains still above the critical range of water scarcity, which would farmers motivate to increase co-operation, and critical water supply multiplier remains close to 1. Payoff ratio multiplier is changing only moderately with a slightly positive effect on co-operation. Hence,

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[6] These multipliers are referred to as Critical Water Supply Multiplier (CWSM), Payoff Ratio Multiplier (PRM), and Critical Agricultural Revenue Multiplier (CARM).

[7] Co-operation multiplier is the product of the three multiplier functions related to water scarcity, payoff ratio, and agricultural production.

co-operation multiplier is above 1 in the first period of 25 years, and below 1 during the second 25 years. As a consequence, co-operation remains on a modest level and is slightly decreasing towards the lower equilibrium (figure 10).

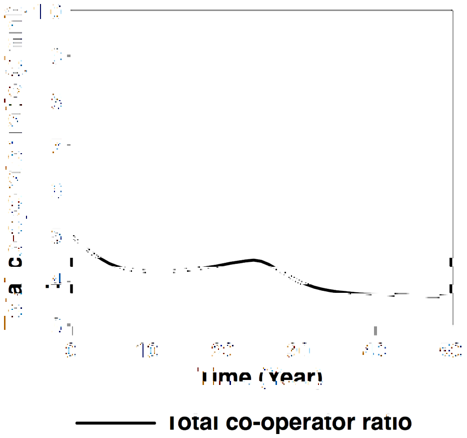

Figure 10: *Basic critical mass model for collective irrigation (base run results): total co-operator ratio remains on a modest level and is continuously decreasing towards the lower equilibrium.*

4.2 Sensitivity analysis

The sensitivity analysis is focused on a variation of the graphical functions, which describe major influence factors for farmers' motivation for co-operation. As such, they capture 'soft' factors related to farmers' interests and assets with regard to irrigation. Not surprisingly, these multiplier functions play a paramount role in the proposed model.

Referring to the multiplier functions presented in figures 5 and 6, it turns out, that critical agricultural revenue multiplier function (CARMF) is the most decisive factor. The earlier onset of the 'good' regime (CARMF 3, CARMF4 in figure 6) is of particular relevance. Payoff ratio multiplier function (PRMF) has a considerable influence as well, indicating that this multiplier also deserves careful investigation. Conversely, critical water supply multiplier function (CWSMF) plays only a minor role in the basic model presented here (figure 11).[8]

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[8] In the extended model, which includes illegal water abstraction upstream, this multiplier plays a more important role. This is due to the fact that for downstream users water scarcity becomes severe at an earlier point of time (Gallati 2008).

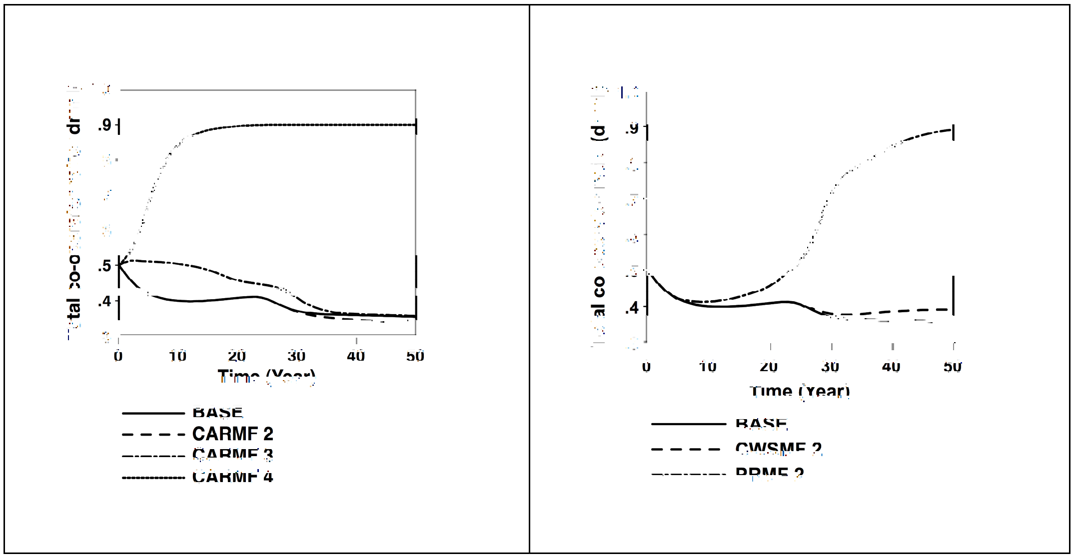

Figure 11: *Sensitivity analysis of the basic critical mass model for collective irrigation: results for total co-operator ratio for a variation of graphical functions. Variation of critical agricultural revenue multiplier function (CARMF), and payoff ratio multiplier function (PRMF) is sensitive for the model outcomes, whereas this pertains to critical water supply multiplier function (CWSMF) only to a minor degree.*

In addition, two conclusions are drawn from the results of this sensitivity analysis. First, further empirical evidence is required regarding these multiplier functions. The general form of these functions, as well as case study specific numerical values should be further investigated. Second, it is argued, that compared to the BASE case, the effect of these multipliers should probably be strengthened, without overruling completely the general dynamics determined by the underlying distribution function. As a result, a probable range for these multiplier functions can be indicated.

5 Discussion and outlook

A basic system dynamics model for collective irrigation management has been proposed, which is aimed at improving the understanding of dynamic processes in collective irrigation systems. In particular, the problem of free-riding on water in irrigation systems has been addressed. A feedback system has been introduced, which builds on the concept of a critical mass and integrates a number of influence factors that have been identified to play a key role for farmers' motivation for co-operation in irrigation.

It has been shown that the base run corresponds to the relatively frequent situation of deteriorating irrigation infrastructure and unsuccessful co-operation. Yet, by varying initial conditions and parameters, the model also describes successful co-operation. In particular, initial condition of co-operation, as well as parameters related to agricultural production, may induce successful co-operation. Moreover, a sensitivity analysis involving graphical functions, which are related to the key influence factors for farmers' choice for co-operation, has been presented.

From a practical point of view the strong influence of agricultural production on successful co-operation is of particular interest. It suggests that efforts aimed at increasing agricultural productivity and water use efficiency create a 'double dividend', improving farmers' livelihoods, as well as stimulating co-operation.

Lines of further activities pertain on the one hand to development and improvement of individual modules, as to enable empirical applications and comparative studies. In particular, a module describing population growth and land use change should be elaborated and included in the proposed model. Moreover, additional empirical evidence regarding the graphical functions is required. In addition, it is suggested to investigate different forms of sanctions and water pricing systems, as to proceed towards a more comprehensive policy analysis.

On the other hand a generalisation of the model is suggested, which involves several dimensions. First, it is proposed to move from homogeneous households to heterogeneous households, which would imply a stratification of the model. This stratification could refer to a socio-economic classification. Even more promising, however, would be a reference to a classification of livelihood strategies, as they are used in studies for sustainable livelihoods.[9]

Second, it is suggested to proceed from a model for collective irrigation to a model for collective natural resource management, such as the management of forests, fisheries, or pastures. Different from irrigation, however, resource consumption becomes dependent on population. As a consequence, population growth is a key component of such a model. Moreover, the state of a natural resource is more difficult to ascertain than the state of an irrigation system. Hence, there is considerable uncertainty about the current condition of the resource, and room for misperceptions (Moxnes 2000).

Third, it is proposed to move from a natural resource model towards an integrated livelihood model. This, however, is a far-reaching vision. As a first step, a dynamic stratified model could be envisaged, where transitions between the strata are included and endogenously calculated. Further development would involve a system dynamics formulation of appropriate sustainable livelihood approaches.

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[9] Livelihood and household strategies are classified in various ways. For an example regarding the classification of livelihood strategies, as well as for further references, see Zoomers (1999) and de Haan and Zoomers (2005).

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