Multi-Agent Simulations to Explore Rules for Rural Credit Management in a Highland Farming Community of Northern Thailand

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Introduction

Thanks to recent advances in the field of distributed artificial intelligence, agent-based models (ABM) can now be used to run simulations of social phenomena based on their computerized representations, and to apply experimental methods in social sciences (Axelrod 1997, Gilbert and Troitzsch 1999, Jager 2000). In the field of renewable resource management and environmental sciences, several ABM simulation platforms offer the possibility to explore interactions between social and ecological dynamics (Costanza and Ruth 1998, Bousquet *et al.* 1998, Lansing 2002). In these complex systems, the social and economic dynamics can be viewed as a set of interactions among heterogeneous agents, generating aggregate phenomena that are different from the behaviour of groups of average individuals considered in classical economic thinking (Rouchier and Bousquet 1998). Such a view was adopted in the research presented here.

The agent-based model presented in this paper was built to explore the interrelated roles of formal and informal credit in a socially heterogeneous community of small farmers exploiting a highland catchment of mountainous upper northern Thailand. Formal credit corresponds to institutionalized credit funds whereas informal credit is seen as loans settled among villagers, either without interests within networks of acquaintances, or with high interest rates when loan sharks are involved.

An original characteristic of the companion modelling approach (Bousquet and Trébuil 2005, http://commod.org) and the simulation process adopted in this case study is the co-construction of the model with the farmers and the use of simulations with them in their village. The objective was to facilitate collective decision-making regarding the adaptation of the local rules for the allocation of rural credit to allow a more equitable and extensive process of expansion of perennial crops (Barnaud *et al.* 2005). Following a description of the methodology and tools used in this experiment, the results of a series of multi-agent system simulations are presented and analyzed. To end with, the specific questions and challenges raised by this type of social modelling and simulation process are discussed, particularly its use and usefulness to local stakeholders.

Materials & methods

Study site

In the Akha village of Mae Salaep located in Chiang Rai province, following more than two decades of integration in the market economy, the process of commercial diversification based on horticultural productions led to an extensive social differentiation among farming households with various economic interests and land-use strategies (Trébuil *et al.* 1997). As the former swidenning system is replaced by (semi-)permanent cash cropping-based agriculture, the increased risk of soil erosion in the upper catchments perceived by lowlanders threatens ethnic minority highlanders with further restrictions regarding their access to farm land. In this context, the expansion of perennial crops is seen as a promising solution limiting soil erosion while securing higher and more stable incomes. But the possibility to invest in perennial crops is highly dependent on access to credit because of the long wait between planting and the first harvests (Barnaud *et al.* 2005).

Formal and informal credit systems co-exist in the village. Concerning formal credit, besides a village fund providing small loans, a government fund providing larger sums, and without interests, was launched in 2002. But this source of credit is currently only accessible to well-off households because they are the only ones who can reimburse the loan on time within a year. This unequal distribution of the government fund is only partially compensated by its redistribution through informal loans within networks of acquaintances. As those networks are usually small and quite homogeneous, there still exists a number of smallholders, acquainted with households as poor as them, with no access to this source of credit.

Characteristics of the companion modelling process

The main principle of the Companion Modelling (ComMod) approach is to alternate field and laboratory activities in an iterative, evolving, and continuous way (Barreteau *et al.* 2003). The ComMod process described here combined the use of field surveys, role-playing games (RPG), multi-agent systems (MAS), individual interviews, and focused group debates among stakeholders.
In this case study, the iterative ComMod process described in Figure 1 was implemented twice between 2002 and 2004. In each cycle, the role-playing game (RPG) used with the villagers is a simplified version of the multi-agent model. The game helps the participants to understand, criticize and validate the model suggested by the research team.

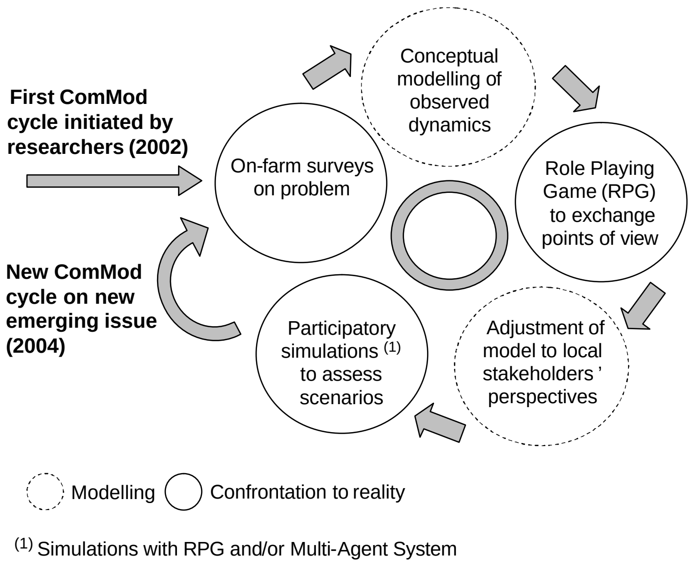


Figure 1. The iterative companion modelling process alternating field and laboratory activities implemented in Mae Salaep village of Chiang Rai Province, upper northern Thailand.

The first cycle focused on reaching a common understanding on the relationship between the risk of soil erosion and crop diversification (Trébuil *et al.* 2002). At the end of this cycle, the villagers validated the agro-ecological aspects of the model, discussed and agreed on the need to expand the coverage of perennial cash crops in the catchment. They also pointed to the fact that only the relatively well-off households could currently invest in plantation crops and requested to implement a second ComMod cycle focusing on the socioeconomic dynamics related to their adoption. In particular, new rules for the allocation of rural credit needed to be found to support the establishment of such plantations in resource-poor farmers' fields.

According to this request, a complementary farm survey was carried out to gather detailed information on these dynamics. New set of Unified Modelling Language (UML) diagrams, RPG and MAS model were conceived to adjust the ComMod process to the villagers' socio-economic preoccupations. A detailed description of the adaptation of the associated RPG and MAS models is available in Barnaud *et al*, 2005. Compared to the initial sophisticated GIS-based model, the new MAS model was simpler, more similar to its associated RPG, to favour its comprehension by villagers. These tools were used with them during a three day long participatory modelling and simulation workshop held in the village school in May 2004 to stimulate exchanges between researchers and local stakeholders, as well as among different categories of farming households. The first day gaming sessions stimulated discussions among the twelve players representing different types of farming households. On the second day, individual interviews were conducted to elucidate the players' behaviours during the game, and to assess the model. On the third day, participatory sessions of simulations with MAS model were conducted to assess the scenarios suggested during the discussions among the participants.

Model description

The multi-agent model was implemented under the CORMAS (Common pool Resources and Multi-Agent Systems, http://cormas.cirad.fr) simulation platform specifically designed to model interactions between ecological and social dynamics for renewable resource management (Bousquet *et al.* 1998).

Modelling assumptions

The three main types of farming households in this Akha village differ by their amounts of land resources and capital: type A holdings are small market integrated farms, type B households are medium-sized and conservative farms, and type C are large farms with diverse commercial productions. Each farming household operates with 1, 2 or 3 family labourers assigned either to off-farm or farming activities. A labour constraint was introduced in the model to reflect the fact that perennial crops are less labour-intensive than annual field crops and allow farmers to seize more off-farm employment opportunities.

Two perennial crops dominate in the catchment: lychee, a high input and high economic risk crop accessible to only well-off farmers, and the more recently introduced green Assam tea, named “the poor man’s perennial crop”. With no external input required, a shorter duration from planting to first pickings, and more stable farm gate prices, Assam tea is accessible to a broader range of villagers, but not all of them yet. In the model’s baseline scenario, as in reality, formal credit is mainly accessible to well-off farmers and is only partially redistributed via small informal loans within social networks. No process of inheritance interferes with the dynamic of investment in perennial crops during the duration of the simulation that does not exceed 15 years.

Model entities and structure

The model main social agents (farmer, loan shark, government and village funds), passive objects (market, weather), and spatial entities (“cell” as the elementary spatial unit on the grid, “fields” of various size depending on the farm type, and “farm” made of several fields) and their relationships are presented in Figure 2. In this UML class diagram, one can see the attributes (variable or permanent characteristics) and methods (possible actions during simulations) assigned to each model’s entity. Twelve agent farmers (3, 6 and 3 for Types A, B, and C respectively) are represented in the model, like in the associated RPG. To represent informal credit, each farmer is assigned two acquaintances selected among the other agents.

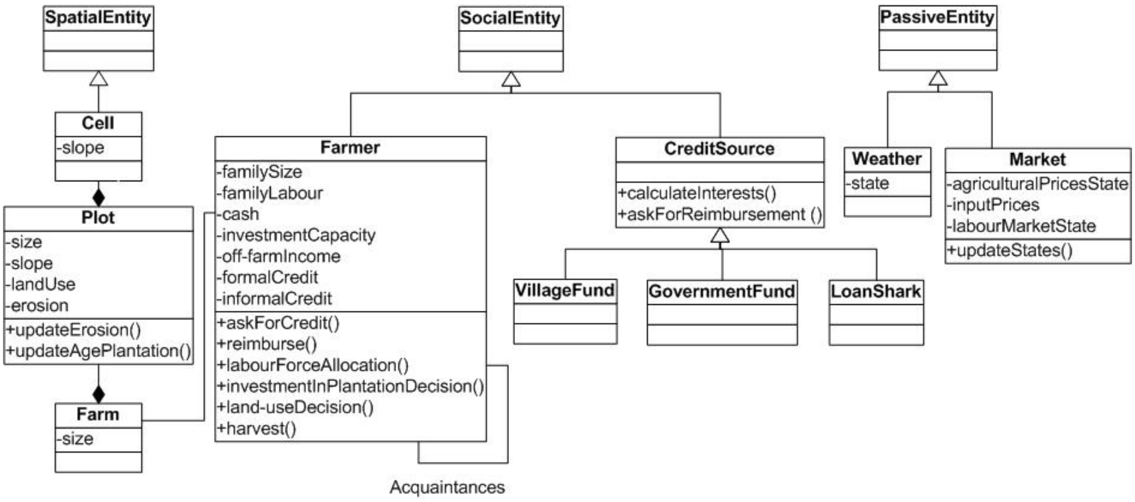


Figure 2. Class diagram of the model describing its entities and their relationships.

Sequential flow of information during simulation

The time step is the crop year and each simulation is made of 15 time steps, i.e. 15 successive crop years. Each year, if credit is needed, an agent farmer will successively try to secure the required loan from the government fund (with zero interest), his acquaintances, the village fund, and, as a very last resort, loan sharks. After looking for credit, each farmer allocates a choice of crops to his fields and the corresponding costs of external inputs are deducted from the available cash. While the decision to grow perennial crops depends on their capacity for investment, the area under annual crops is mainly regulated by the amount of family labour available. The amount of family labour available depends on the farmer’s decision to seize off-farm employment opportunities or not. After these steps, the model simulates the harvesting period (sale of cash crop products and deduction of the family consumption) and proceeds with the reimbursement of the loans to each lender. When a farmer cannot reimburse a loan secured from the formal credit system, he will request credit from acquaintances and loan sharks. A farmer indebted with loan sharks assigns all his family labour to off-farm activities. If this is not enough to reimburse the loan, this agent disappears because he/she is forced to sell the farm land and to leave the village.

Outputs and indicators

Two major indicators were selected to assess the results of the simulations: (i) an agro-ecological indicator: the area under perennial crops for each of the three farm types, and (ii) a socioeconomic indicator: the percentage of farming households facing bankruptcy and having to leave the village against their will due to indebtedness.

Verification and calibration

The model verification and calibration were carried out by using a year-by-year monitoring of a set of indicators during simulations (crop combination per type of farm, on/off-farm labour employment, annual net incomes) and through their qualitative and quantitative comparison with the real circumstances recorded during the preliminary farm surveys.

Validation: respective roles of modellers and stakeholders

A definition of validation suggested by Moss et al. (2000), and adopted here, is "the process by means of which model users develop confidence that the simulation models accurately capture their own assumptions". The game, very similar to its associated model, is a useful tool to "open the black box of the model" to facilitate its understanding by local stakeholders and to allow them to participate in its construction and validation (Barreteau et al. 2001). During the gaming sessions and the following interviews, the players were asked whether some important dynamics related to the problem were missing or were not well represented compared to their assumptions about real circumstances. If a few suggestions for improvements were made and integrated in the model, in particular regarding the calibration of off-farm incomes, most of them declared that "it is exactly like in reality!".

Identification of scenarios according to stakeholders' suggestions

The gaming session revealed the social inequity regarding investments in plantation crops because of unequal access to credit. The participants agreed that this situation reflected their real circumstances and constituted a problem. This collective agreement stimulated more exchanges and the following questions were raised: how to change the rules for formal and informal credit so that resource-poor type A farmers would have a better access to credit? Is it possible to change those rules? Would the smallholders benefit from such a change or would they face an even higher risk of bankruptcy? What would be the consequence of such changes for the medium-sized and larger landholders (type B and C farms)? Following a lively discussion, they proposed to explore two possible solutions. An old player suggested to solve the problem through informal credit, i.e. to set up broader and more socially heterogeneous networks of acquaintances to allow smallholders who are not yet acquainted with some wealthy farmers to get informal credit from them without interest (Figure 3). Younger players suggested to change the rules regulating the allocation of formal credit. In the current situation, type A farmers do not have access to the government fund, and the grace period is one year. These players suggested to introduce a 3 year long grace period (3 years is the duration from planting to first harvest of perennial crops in the model), and to allow type A farmers to borrow money from this source.

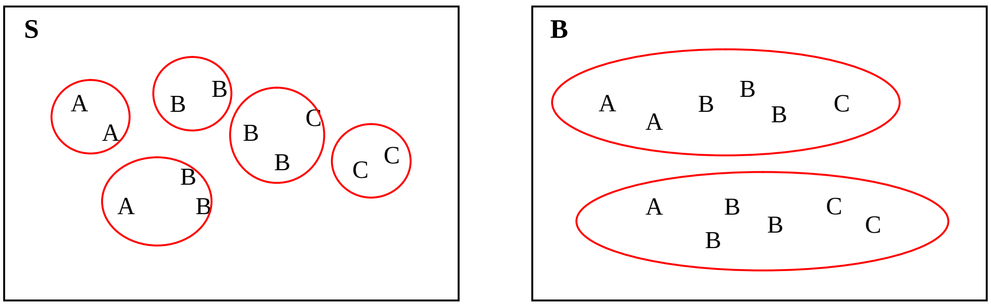


Figure 3. The two (S, B) types of social networks among three (A, B, C) main types of farms in the village used to regulate the distribution of informal credit. S: small and rather homogeneous networks (close to the real circumstances), B: broader and more heterogeneous networks. Type A, B and C farms are respectively small, medimum-sized and large farms.

Six scenarios considered as pertinent to further stimulate the collective exchange were defined based on different combinations among the following three variables (Table 4):

(i) Duration for the reimbursement of loans secured from the government fund: one or three years (1,3),

(ii) Mode of allocation of formal credit from the government fund among the three different types of farms : two main types of distribution are distinguished whether this source of credit is accessible to type A farmers or not (A for Access, NA for No Access)[1],

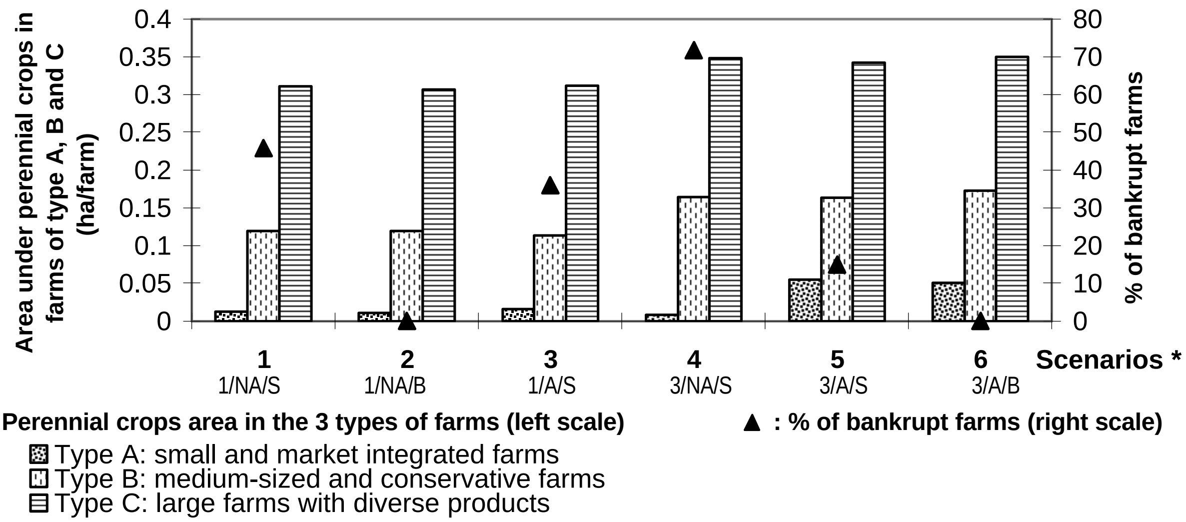
(iii) Configuration of networks of acquaintances for access to informal credit: two situations displayed in Figure 3 (S for Small networks, B for Broad networks).

Table 4. Description of the six scenarios to be simulated in this experiment.

Scenario	**1**	**2**	**3**	**4**	**5**	**6**
Duration of loans from government fund (years)	1	1	1	3	3	3
Distribution of loans from government fund (A or NA for Access or No Access for type A farmers respectively)	NA	NA	A	NA	A	A
Configuration of networks of acquaintances for informal credit (Small or Broader, S or B respectively)	S	B	S	S	S	B

Results of simulation experiments

Figure 5 displays the results of the simulations of the six selected scenarios. The graph displays the area under perennial crops in the 3 types of farm and the percentage of bankrupt farms at the end of the simulations, i.e. 15 years.



Note*: scenarios are combinations of 3 variables : the duration of government credit (1 or 3 years), its distribution (A or NA for Accessible or Not Acessible to type A farmers), and the configuration of acquaintance networks (S or B for Small or Broad).

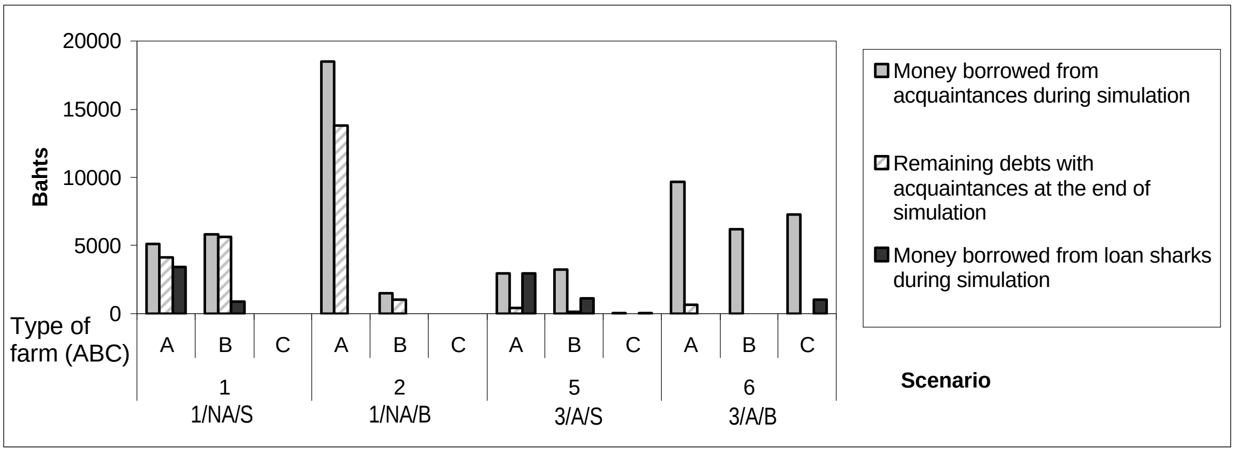
Figure 5. Effects of various rules for the allocation of formal and informal credit on the adoption of perennial crops and the risk of bankruptcy among different types of farmers.

Scenario 1 (1, NA, S) is the baseline scenario corresponding to the current situation: it is characterized by a 1 year grace period for the loans secured from the government fund (1), no access to this fund for smallholders - type A farmers- (NA), and small and rather homogeneous networks of acquaintances (S). Scenario 2 (1, NA, B) explore new rules for informal credit, and more precisely broader networks of acquaintances. The results suggest that under those circumstances, i.e. when smallholders have more the possibility to borrow money from acquaintances, the number of farms going bankrupt in the community is significantly reduced. But the results also suggest that this does not allow these smallholders to increase their capacity to invest in plantation crops. This is because farmers borrow money from their acquaintances only for urgent family needs, not for long-term investments like plantation crops. In scenarios 3, 4, and 5, networks of acquaintances remain small like in the baseline scenario, and new rules for the allocation of formal credit are tested. In scenario 3 (1, A, S), type A farmers have access to the government fund, but the duration of the loan remains 1 year. Another set of

[1] For 1 year long credit : "NA" distribution corresponds to Baht 0, 10, 20 thousands for farm type A, B and C respectively; "A" distribution corresponds to Baht 5, 8, 19 thousands for A, B, C farms respectively. For 3 year long credit : "NA" distribution corresponds to Baht 0, 30, 54 thousand, and "A" option to Baht 12, 18, 54 thousands.
NB: in early 2006, 40 Thai baht= 1 US$.

simulations (not presented here) quantified the amount allocated to type A farmers in this scenario. The main criterion was the farmers' reimbursement capacity, i.e. the maximal amount that type A farmers are able to reimburse without reaching certain bankruptcy. The results of scenario 3 suggest that such a loan is not sufficient to allow them to invest in plantations. This is because farmers have to wait three years before getting the first harvest of their perennial crops– and be able to reimburse a loan. In scenarios 4 and 5, the reimbursement period is 3 years. The loans are therefore almost three times higher than in scenarios with 1 year long credit. In scenario 4 (3, NA, S), type A farmers do not have access to this fund, and the total amount is shared among type B and type C farmers only. Results of simulation suggest that a 3 year long credit allows type B and C farmers to grow more perennial crops. It also shows that when amounts allocated are too high compared to farmers' reimbursement capacity, the risk of bankruptcy increases : this is what happens to type B farmers in this scenario. In scenario 5 (3, A, S), the total amount of credit is shared among the 3 types of farmers. This scenario suggests that if amounts allocated are not too high (compared to each type of farmer' reimbursement capacity), a credit with a 3 year long grace period allows all types of farmers (including smallholders) to grow more perennial crops. However, in spite of the higher income generated by these plantations, the risk of bankruptcy remains above 15%. Only broader newtorks of acquaintances allow to reduce very significantly the risk of banbkruptcy, as illustrated by the results of scenario 6 (3, A, B). These 6 scenarios illustrate the specific and complementary roles played by formal and informal credit. Formal credit is potentially more efficient than informal credit to stimulate investment in perennial crops, whereas informal credit is potentially more efficient than formal credit to reduce the risk of bankruptcy.

Figure 6 displays the informal exchanges among agents (with acquaintances and loan sharks) during simulations of scenarios 1, 2, 5 and 6.



Note 1: as farmers who cannot reimburse their loans with loan sharks go to bankrupt, there are no remaining debts with loan sharks at the end of the simulations. Note 2 : scenarios are combinations of 3 variables : the duration of government credit (1 or 3 years), its distribution (A or NA for Accessible or Not Acessible to type A farmers), and the configuration of acquaintance networks (S or B for Small or Broad).

Figure 6. Farmer behaviour regarding informal credit during simulations.

There are more exchanges among aquaintances in scenarios 2 and 6 (broad networks of acquaintances) than in scenarios 1 and 5 (small networks of acquaintances). This result was quite intuitive. But if one compares results from scenarios 1 and 2 (one year long credit non accessible to type A farmers) with those from scenarios 5 and 6 (3 year long credit accessible to type A farmers), a non-intuitive result is that even when formal credit is accessible to all types of farmers, informal credit with acquaintances remains very important. This is because farmers borrow money from their acquaintances when they need to reimburse formal loans. But the difference between the two situations is that there are less remaining debts with acquaintances at the end of simulations in scenarios 5 and 6 when formal credit is more accessible. This is because under these scenarios, rules of formal credit allowed farmers to invest in perennial crops: they were able to reimburse their debts to their acquaintances thanks to the higher incomes from their plantations. However, it would be too simple to conclude that the suggested new rule of allocation of formal credit is the "best" solution. Indebtedness with loan sharks remains significant in scenario 5 and can only be reduced through broader networks of acquaintances like in scenario 6. This confirms that formal and informal credit play specific and complementary roles and that they should be jointly taken into account and analyzed when looking for improvements in credit management.

Discussion

The researchers could run simulations on a model integrating villagers' preoccupations and perceptions. This allowed them to better understand the functioning of the complex credit system under study. Agent-based modelling looking at social and economic dynamics as a set of interactions among heterogeneous agents within networks allowed an in-depth analysis of informal credit mechanisms. Their specific roles in the community, and strong linkages with formal credit were elicited. This is a key finding that researchers could have neglected if another kind of model had been used.

As for villagers, they said that requests for the establishment of a three year long grace period on loans from the government fund had already been sent to the government authorities by many rural communities across the country. "If tomorrow the government agrees to lend us money for three years, we would have to adapt rapidly to the new situation and these tools could be helpful" said a villager. The proposed companion modelling process "helps to think ahead (…) In our every daily life we do not have the opportunity to think ahead like this" declared a participant. This is because over a single gaming session, players are able to observe and assess the effects of their successive choices for six cropping years, and even more – and far more rapidely- with the simulations. The gaming and simulation tools stimulated a collective learning process among the villagers: they could suggest & explore scenarios for the management of rural credit that took into account both formal and informal sources, trade-offs between socio-economic & ecological objectives, as well as equity issues among their heterogeneous farming community.

The use of social simulations with local stakeholders has two major implications. First, an important challenge for the research team is to avoid the risk that local stakeholders view the results of these social simulations as quantitative predictions of the future. The model should be seen as a mean to collectively discuss possible options before any technical decision is considered. The associated RPG is a key tool to ensure that the functioning of such models and, more importantly, their limits, are well-understood by local stakeholders. Second, to increase the usefulness of these social simulations to local stakeholders, the models (the RPG as well as the computerized ones) need to be constantly updated and adapted to their representations and evolving preoccupations during the companion modelling process. Moss and al. (2000, p.4) broadly define validation as "the process by means of which software systems are demonstrated to satisfy the requirements of the users". Two time scales are distinguished in this process of adaptation of the model to the requirements of the users. Within a ComMod cycle, participants are asked whether the model fits to their representation of the problem at stake and the model is modified accordingly. The longer term validation process is more unusual in social simulations. It corresponds to the evolutions from a Commod cycle to a following one: after validating a model within a ComMod cycle, the use of this model by users stimulates discussions and might raise new questions and corresponding new requirements. A new model is then built to fit to these requirements. Each model is seen as a subjective extraction of the key relevant dynamics of the system at a particular moment of a collective learning process among a particular set of stakeholders with specific needs and expectations.

Conclusion

This experiment suggests that the usefulness of models relies much more on the modelling process than on the model itself, because a model is usually useless if it is misunderstood by its potential users, or if it does not respond to their current preoccupations. The most useful models for stakeholders are not necessary the most comprehensive and sophisticated ones. Very adaptive models seem to be more appropriate. Such an adaptive co-construction of the models with stakeholders implies modellers' willingness to adjust them to stakeholders' changing preoccupations, and the choice of very open and flexible modelling processes and tools. Agent-based modelling can respond to these needs as it offers the possibility to add or delete agents or to modify the model features and object behaviour without having to rebuild the whole model.

The process of adaptive and collective construction of the model is therefore seen as essential to guarantee its usefulness. This way to approach the notion of "model" raises questions such as: what would be the scientific status of a false model approved by the stakeholders? A first empirical way to answer to this question is to observe that among the numerous ComMod experiments conducted during the past 6-7 years in different regions of the world, such a situation never occured. From a theoretical point of view, this empirical observation is not really surprising because one of the hypothesis of participatory approaches is precisely that all stakeholders have their reasons to act the way they act, and that the role of the scientist is to understand these reasons. However, the researchers should have a critical analysis of these reasons. If the risk to build a "false" model exists, it probably comes from the risk of manipulation of the modelling process by some powerful local stakeholders. And on the other hand, there is also the risk to build a model that doesn't include the perceptions of the voiceless people. There is a need to elucidate and take into account the differentiated ability, and will, of the various local stakeholders to genuinely participate in the modelling process. In ComMod, researchers are seen as implicated stakeholders participating to the co-construction process, and an initial analysis of institutions and power relations to ensure a genuine participation of all stakeholders in the process can be seen as one of their contributions.

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