Economic differentiation of rice and shrimp farming systems and riskiness: a case of Bac Lieu, Mekong Delta, Vietnam

Le Canh Dung, Nguyen Nhi Gia Vinh, Le Anh Tuan, and F. Bousquet

In production terms, Bac Lieu Province in the Mekong Delta of Vietnam is characterized by rice and saline-water shrimp farming. This paper presents two simulation models of economic differentiation of those farming systems.

The first model simulates observed farmers' behavior in six different farming subzones of the province. After simulating 5 years for each farming system corresponding to each subzone, the results showed that economic differentiation has occurred in every subzone at the study site in terms of both household average accumulation of income and number of households in the rich and poor class. The household average accumulation of income of the rich household class in those subzones where physical conditions allowed shrimp farming has a high value, while that of the medium and poor households remains at a low value, and is even negative for two subzones. The household average accumulation of income of the rich household class in those subzones where physical conditions (freshwater zone) allowed only rice farming reaches a high value after 5 years of simulation, but this value is still less than that in shrimp-culture subzones. The poor households in these subzones of rice-based farming also face a negative income after some years.

The second model aims at simulating changes in cropping system under various conditions. The individual decision-making process is based on a theoretical model, the Consumat. Scenarios based on alternative values of prices, yields, risk, and size of networks are compared. It is shown that prices and shrimp yields make the difference in terms of both wealth and economic differentiation.

Bac Lieu, in Ca Mau Peninsula, is one of 12 provinces of the Mekong Delta in Vietnam (Fig. 1), where about 85% of the population is engaged in agricultural and fishery activities, with rice cultivation being the most important (Hoanh et al 2001). The combination of farming and livelihood as well as the interactions between biophysical and social factors are complex. Therefore, we want to clearly understand them, especially over time. Different farming systems and thereby income are major issues being taken into account. This is because the evidence showed that monoculture of shrimp has a high return but also a high element of risk (Hossain et al 2002), whereas rice farming has a low benefit but is much more stable. The questions raised over time are (1) Is there a differentiation in income distribution at the household level because of the biophysical conditions and market factor? (2) Is there a differentiation in household income within the subzone because of biophysical conditions and hetero-

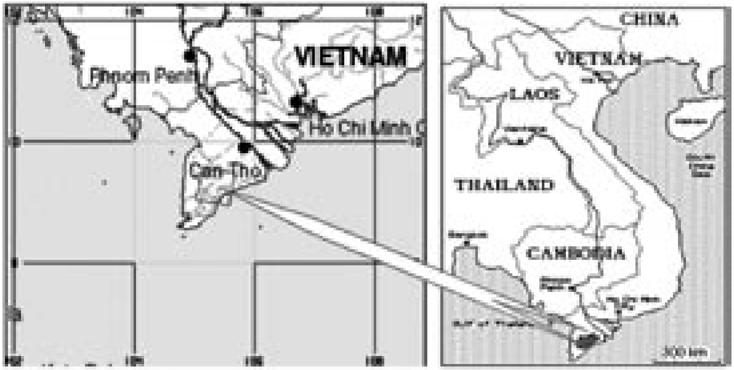

Fig. 1. Location of the study site in the Mekong Delta of Vietnam.

geneity in farm management knowledge? (3) How will the differentiation evolve if the farmers change their behavior? In this research, the first two questions are discussed by running a simulation model based on the observations of farmers' decisions for six different zones and the third question is discussed by running a simulation model using a theoretical model of the decision-making process, the Consumat approach (Jager 2000).

A multi-agent systems (MAS) model supported by the CORMAS (common-pool resources and multi-agent systems) program helps us to answer those questions. It allows us to visualize the scenarios after linking several biophysical and socioeconomic factors. Consequently, given the complexity of this subject, the spatial characteristics, and, above all, the noneconomic and interactive behavior of farmers, we use the MAS model to simulate the scenarios. This paper presents first the background of the study and a brief review of applications of MAS for water management and economic differentiation. Then, a first model is conceptualized and simulated to explore the consequences of the actual behavior of stakeholders. A second model, more abstract, explores the consequences of the changes in behavior and the relative effects of various driving forces.

Background

This coastal province has recently experienced a large conversion in land use. The original objective was to shift from the natural exploitation of fisheries and a single traditional rice crop to modern double and triple rice crops. The conversion relied upon changes in water resource-use strategy. In the early 1990s, in response to the country's high demand for rice, the government constructed a series of embankments and sluices along the coast of Ca Mau Peninsula. The purpose was to (1) build a series of sluices that could be closed at flood tide to protect rice lands from saline intrusion and (2) improve the canal networks to increase the supply of fresh water from the Mekong River. The total area that the project could protect was 250,000 ha, of which approximately 160,000 ha belonged to Bac Lieu Province. This resulted, as intended, in the rapid expansion of intensified rice cultivation and a sharp decline in shrimp farming in the project area.

An intervention such as that does not always have a positive environmental and socioeconomic impact because of the rapid change in hydrological conditions. The impact varies with farmers' production conditions and their environment. The farmers on nonacid sulfate soil in the east of the project area benefited from the saline protection scheme, which allowed them to increase rice intensification. In contrast, farmers in the acid sulfate soil in the western part found themselves having to abandon their shrimp farming, which in some cases meant a sharp decline in household income. The change in environment also caused a decline in income earned from capture fisheries, which were not only an important income source for poor households but also their major protein source (Hoanh et al 2001).

Recently, the high profit of shrimp and low profit of rice production have had a strong economic impact on those who had converted from shrimp to rice cultivation. Moreover, unproductive rice production in the acid sulfate soil area, especially in the western part belonging to the project area, led to a great loss of both farmers' income and government revenue. This prompted the government to re-examine the original development objective. Since 2000, the policy had to change to two distinct water-control schemes. In the eastern part of the project area, the first scheme is preventing saline-water intrusion while supplying more fresh water to develop rice-based farming. The second scheme, applying to the western part, is alternatively allowing saline water in the dry season and keeping fresh water in the rainy season for shrimp and rice culture, respectively. The project area can now be separated into six subzones, in which subzones 1, 2, and 3 follow the first water scheme and subzones 4, 5, and 6 follow the second water scheme (Hoanh et al 2001; Fig. 2). Over five years, farmers in the project area have faced great difficulty in coping with variation in environment and their strategy of resource use. This brought about a strong requirement of technical and socioeconomic assessment and research from government and research institutions. The integration of knowledge on biophysical and socioeconomic factors is being taken into account as a prerequisite in this context. In 2000-03, a DFID project carried out a study on research knowledge, technologies, and recommendations on natural resource use at both the farm household and commune level. The study confirmed that the environment and resource use in coastal lands are very sensitive to external intervention (Hossain et al 2002).

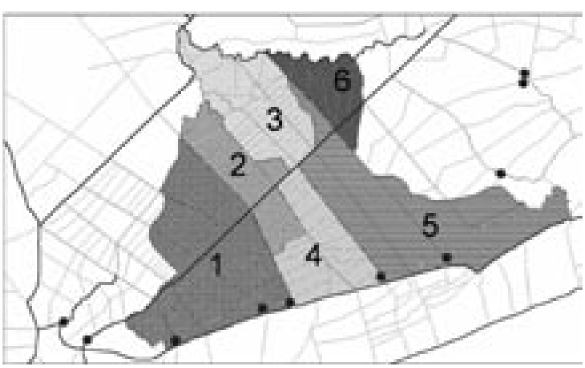

Fig. 2. Six subzones at the study site in Bac Lieu, Mekong Delta, Vietnam. The dots represents the sluices.

Literature review

MAS and water management

Multi-agent systems are increasingly used in the field of environment and natural resource management (Doran 2001). MAS combine the advantages of cellular automata and multilevel modeling since these are able to represent both interactions between individuals and between different levels of organizations (Gilbert and Troitzsch 1999). MAS have proved to be very useful for taking into account several kinds of anomalies that cannot be explained with other models (Bousquet et al 1999). MAS are used to show the observed dynamics of the system to stakeholders (including noneconomic interactions and long-term strategies of users). Multi-agent systems have proved to fit very well with these kinds of goals (Barreteau and Bousquet 2000, Deadman et al 2000, Ferber 1999, Janssen 2003, Rouchier et al 2001). For water management, several attempts have been made to model the interactions between resource dynamics and societies.

MAS were useful for the integrated management of the use of the water table of the Kairouan region in Tunisia. They were useful in representing a complex and distributed system of the water table. They can explore the interactions between the physical and socioeconomic components of the system (Feuillette et al 2003). Recently, multi-agent modeling has enabled horizontal relationships (spatial configurations) and vertical relationships (socioeconomic organization) to be integrated for predicting not only the duck population but also the economic conditions under an exchange between decision-making of farmers and hunting rights in the Camargue, in the South of France (Mathevet et al 2003). The multi-agent approach is applied to model and simulate hydraulic management in the Camargue (Franchesquin et al 2003). In this model, hydrologic and human decisions are integrated and two models are defined. The first one computes the hydro-saline state of the Vacarres region according to natural factors (rain and evaporation) and human factors (irrigation, drainage, and management of the dike). The second one formalizes decisions on hydraulic management in the two phases of the life cycle of a contract. For the Tisza River in Hungary, a simulation model using the Consumat approach (Jager 2000) to evaluate alternative flood management policies is used. This is because one cannot predict the time, location, and magnitude of floods in the case of limited historical data (Brouwers and Verhagen 2003). In the model, the behavior of the river and the financial consequences are simulated on a year-by-year basis. The extension of the model has been successful as results are more in line with the real world. So, MAS are very useful for integrating several aspects that one wants to take into account.

MAS and economic differentiation

It is evident that MAS can integrate socioeconomic, ecological, and spatial dynamics into one single model. In a diffusion process, the agent-based model is explored as a bottom-up approach to make a good prediction of the dissemination of a good in the market, for which the outcome is consistent with results produced by the top-down approach using the Bass model (Holanda et al 2003). The economic behavior of human beings is much more closely related to cognitive science, in which the emotions of a human being are more flexible and decision-making is more rational. Under this concept, four styles of decision making come from the combination of two reasons and autonomous dimensions followed by individual and social dimensions of cognitive processing. These are repetition, deliberation, imitation, and social comparison behaviors. Repetition behavior occurs when consumers have a high level of need satisfaction and certainty; deliberation behavior occurs when consumers have a low level of need satisfaction but have high certainty; imitation behavior occurs when consumers have a high level of need satisfaction but have uncertainty; and social comparison behavior occurs when consumers have a low level of need satisfaction and low certainty (Jager 2000). This model assumes that an agent has four kinds of decision-making process:

- *Repetition*. The agent just keeps on making the same decision.
- *Imitation*. The agent imitates the decision of other agents he is connected with.
- *Deliberation*. The agent will compare the potential options and select one of those.
- *Social comparison*. This is the same procedure as the imitation, but, before adopting a new activity, the agent checks whether the new activity has a better expected output than the current one.

As in Bac Lieu, decisions are closely linked to risk. In this case, the Consumat approach is useful for modeling the changes in behavior.

First model: simulating actual dynamics and consequences on economic differentiation

Methodology and approach

A companion modeling approach is applied for this model. The research questions came from field observations and discussions among scientists that took place at an interdisciplinary meeting in Ho Chi Minh City in late 2000 and from information gathered from the baseline survey, participatory rural appraisal (PRA), and full household socioeconomic survey in previous research projects implemented in Bac Lieu Province. Bac Lieu was the site for investigation, especially after the saline protection project went into operation. A baseline sampling survey of 350 households took place in early 2000 (Gallop et al 2002). A PRA and a full household socioeconomic survey in five hamlets of the project area were conducted in mid-2000 (Hossain et al 2002). A key informant interview was done in late 2002 and a final survey and PRA were made in early 2003 to assess livelihood dynamics under 3 years of readjusted land-use strategy. After building the model for the simulation for 260 time-steps, in which one step is equivalent to 1 week, the model is run. An important aspect of our model is that the simulation results are validated by revisiting the six communes to verify the results with local people (Fig. 3).

Available knowledge and data

From the baseline sampling survey, we learned that in 350 households interviewed the family size averaged 5.23 persons, and ranged from 1 to 13. Rice production is the dominant cropping system, and it occupies 75.8% of the total parcels in the survey, followed by aquaculture and fisheries. Average rice yield surveyed was 3.29 t

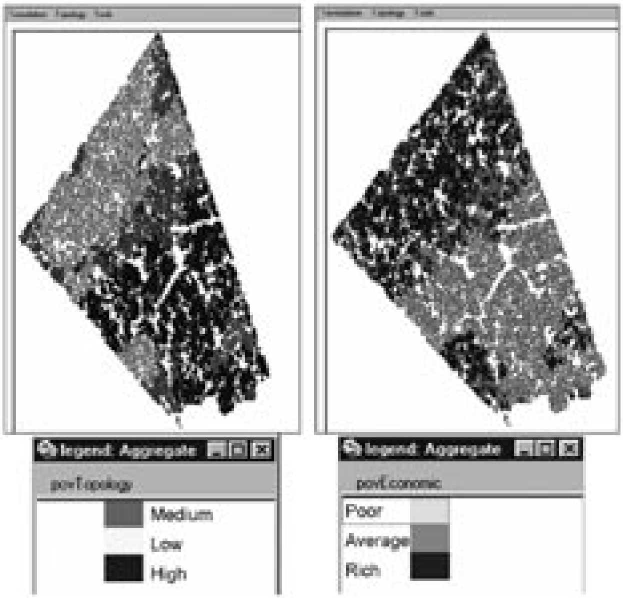

Fig. 3. The companion modeling approach.

ha^{-1}, which could be seen as a reasonable yield in acid sulfate soil conditions under controlled irrigation. A double rice crop is the major pattern among rice production systems; this type of crop represented 64.3% of the total parcels in the survey. Rice could be sold at an average price of 1,602 Vietnamese dong[1] (vnd) kg^{-1}, and ranged from 800 to 3,200 vnd kg^{-1}. Therefore, the profit that could be obtained from rice production was 885 vnd kg^{-1} of paddy; consequently, rice farmers could earn a profit of 6 million vnd per household per year. However, because of uncertainty and farm size, the profit differed markedly, from –12 million to +67 million vnd per year per household. Some 42.9% of the total households surveyed engaged in aquaculture and fisheries, but only 22.5% of the households practiced shrimp/fish production. Profit from this sector varied widely, from –15 million to +216 million vnd per household per year. The semistructured interviews done in six communes also showed that, among the vast number of farmers doing extensive farming of shrimp, some advanced farmers have improved their shrimp production by changing from extensive to semi-intensive shrimp ponds, which they expected would earn a higher profit. One advanced farmer interviewed could harvest 500 kg of shrimp ha^{-1} under the semi-intensive raising method. This key informant interview also showed a variation in rice and shrimp production and their prices, as well as among the subzone after readjustment of the land-use strategy (Table 1). At the prevailing price of rice and shrimp and with the low yield under extensive shrimp cultivation, fish production is about five times more profitable than rice production. As a result, the socioeconomic survey estimates the negative effect at 39% of household income during the transitional period, and 17% at full development.

[1]US$1 = 15,000 vnd.

Table 1a. Parameters of rice and shrimp production by subzone in the study area.

Subzone	Rice yield (t crop^{-1} ha^{-1})			Rice price (vnd kg^{-1})	Rice cost (million vnd crop^{-1} ha^{-1})
	Highland	Medium land	Lowland		
1	3.5–4.0	No rice	No rice	1,500	3.5
2	1st: 2.5–3.5	1st: 2.5–3.0	3.0	1st: 1,300	1st: 3.5
	2nd: 3.0–4.0	2nd: 3.0–3.5		2nd: 1,200	2nd: 3.4
3	1st: 4.0	1st: 3.5	4.0	1st: 1,700	1st: 4.0
	2nd: 3.0	2nd: 3.0		2nd: 1,700	2nd: 4.0
4	1st: 5.4	1st: 4.6	1st: 3.8	1st: 1,750	1st: 3.5
	2nd: 4.6	2nd: 3.8	2nd: 3.0	2nd: 1,600	2nd: 3.5
5	1st: 6.2	1st: 4.6	1st: 4.2	1st: 1,800	1st: 2.0
	2nd: 5.4	2nd: 4.6	2nd: 4.2	2nd: 1,700	2nd: 1.5
	3rd: 4.6	3rd: 4.2	3rd: 3.0	3rd: 1,700	3rd: 1.5
6	1st: 4.5	1st: 4.0	1st: 3.5	1st: 1,600	1st: 3.2
	2nd: 5.0	2nd: 4.5	2nd: 4.0	2nd: 1,500	2nd: 3.5
	3rd: 3.5	3rd: 3.0	3rd: 3.0	3rd: 1,500	3rd: 3.5

Table 1b. Parameters of shrimp production by subzone in the study area.

Subzone	Shrimp yield (kg crop^{-1} ha^{-1})			Shrimp price (vnd kg^{-1})	Shrimp cost (million vnd crop^{-1} ha^{-1})
	Highland	Medium land	Lowland		
1	1st: 0	1st: 50	1st: 60	1st: 100,000	
	2nd: 20	2nd: 50	2nd: 80	2nd: 100,000	15.0
	3rd: 80	3rd: 80	3rd: 100	3rd: 100,000	
	4th: 80	4th: 80	4th: 120	4th: 100,000	
2	No shrimp	No shrimp	300	100,000	5.0
3	No shrimp	No shrimp	100	100,000	5.0
4	No shrimp	No shrimp	No shrimp	–	–
5	No shrimp	No shrimp	No shrimp	–	–
6	No shrimp	No shrimp	70	80,000	5.0

Source: Key informant interviews in study area carried out in December 2002.

So, thanks to the available knowledge and the typical biophysical conditions, especially in the different farming systems in the six different subzones of the research area, the six communes corresponding to each subzone were chosen for incorporation into the model.

Conceptualization of the model

The model was based on a series of assumptions, as follows. There are six communes with different topology and number of households. Farmers that live in the six communes plant different crops and have different knowledge. Almost all of them have land for planting rice or raising shrimp; the rest are landless people that have different characteristics and experience, who can choose different job opportunities for earning money, such as fishermen, hired laborers, seasonal migration, and sellers. In this model, farmers' living costs are already taken into account. The number of households and their distribution in three economic categories (poor, average, and rich) were given by the data of the baseline sampling survey, BSS (Table 2). Poor farmers receive a plot of 0.5 ha, average ones a plot of 1.5 ha, and rich ones a plot of 3.5 ha. The plots are randomly placed on the map. The farmers also receive various amounts of money at initialization (Fig. 4).

Table 2. Number of households by economic class in six selected communes.

Class	Number of households by commune					
	1	2	3	4	5	6
Poor	996	552	728	830	803	735
Medium	1,546	1,540	1,943	1,106	987	1,648
Rich	961	995	508	585	283	734

Source: Baseline sampling survey carried out in 2000.

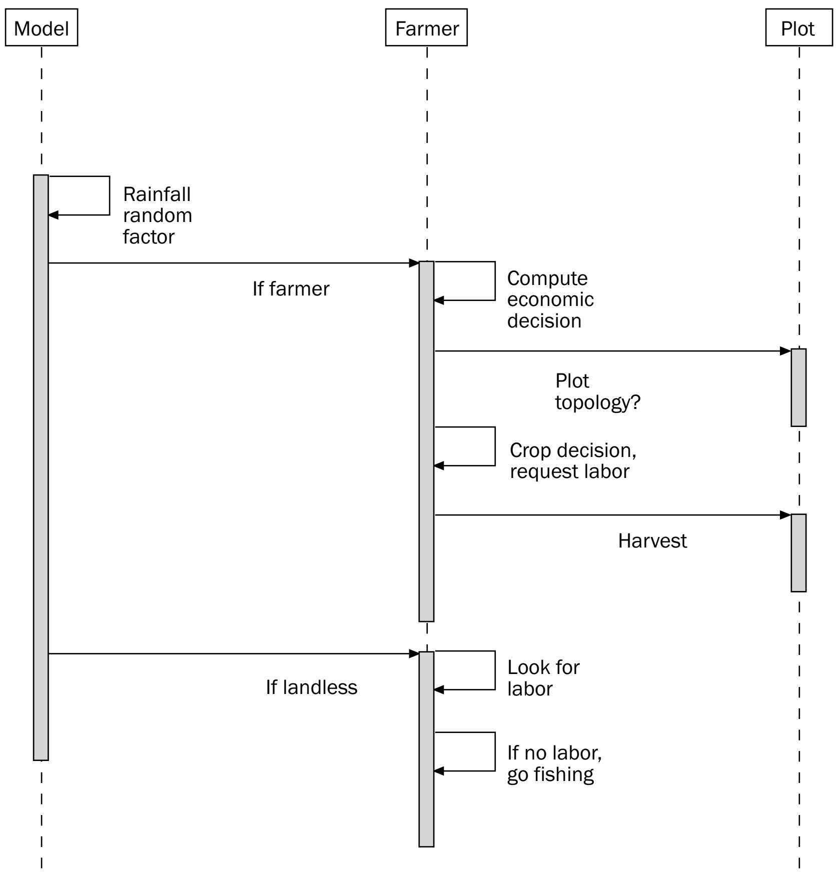

Fig. 4. Topology and economic conditions of commune 1.

The following factors are taken into account:

- The climate is separated mostly into two seasons: dry and wet. The status of sluices is determined by the wet season. When the wet season arrives, the sluice is closed and vice versa. The climate factor can be a random factor in this model.
- Choosing farmers' crops (rice, shrimp) depends mainly on the economic conditions, type of land (high, medium, or low), and the status of sluices in the region (open or closed). The decision-making process schedule appears in Figure 5. In some regions, farmers plant a rice crop in rotation with a shrimp crop to improve biological conditions and increase shrimp quality for later crops.
- The appropriate time scale to represent the changes in the model is the week because, after several weeks, farmers harvest a crop and prepare for the next crop. Therefore, in one year, they can have more than two rice or shrimp crops.

Harvest time can be a random factor. Farmers harvest at a time from the 15th to 17th week for the rice crop and 14th to 16th week for the shrimp crop before the end of the crop because other environmental factors can affect the growing of rice or shrimp; this means that the harvest time cannot be fixed from year to year.

Implementation of the model

We use CORMAS as a tool to simulate the BACLIEU model. This tool is based on the platform VisualWorks®, a programming environment software used for programming in Smalltalk® object-oriented language (Bousquet et al 1998). In CORMAS, an agent or entity can be described as autonomous because it has the capacity to adapt when the environment changes. In addition, CORMAS helps us create relationships in communication and situations between entities or agents. The BACLIEU model has three main entities: (1) the spatial unit, "cell," which can be regarded as the smallest land area of 1 ha; the other is the "plot," which aggregates cells together to form bigger land areas and to separate one land area from others; (2) "farmer" is the social entity; each farmer can exchange messages with others; and (3) the passive entities "rice" and "shrimp" are specified as crops. Each plot instance is assigned to a farmer instance. Each farmer instance can have no plot or only one plot. A landless farmer can be a hired laborer or choose another job to do. Farmers can perceive what happens

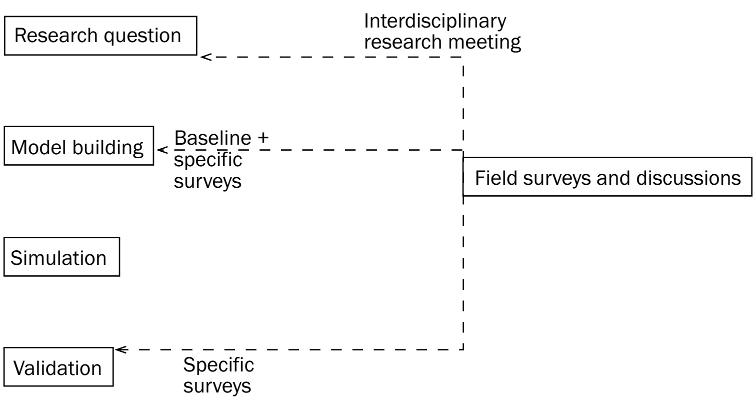

Fig. 5. The sequence diagram of the BACLIEU model.

in the environment so that they can decide which crop they want to plant. Each farmer instance receives a status of sluice and rainfall; harvest time of shrimp and rice come from passive objects, including shrimp, rice, sluice, and rainfall.

Results and discussion

Farming systems, average accumulated household income, and the number of different household classes are visualized in this model. Average accumulated household income is a return above the variable production cost plus family living cost. Results are presented for different classes of agents: class A stands for rich farmers who have more than 250,000 vnd, class B stands for those who have from 100,000 to 250,000 vnd, class C for those who have less than 100,000 vnd, and class D for the landless agents. In this scenario, the model is run for 260 time-steps (1 week = one time-step) equivalent to 5 years. The simulation results from six communes are summarized. We can state that the two important research questions are economic differentiation (1) among subzones and (2) within subzones. The results are presented in Figure 6. Line A represents the rich households, line B the medium households, line C the poor households, and line D the landless households.

In commune 1, there is a large economic differentiation after 5 years of the simulation, reflected in the average accumulated household income among household types and the variation of those households. Income and number of rich households are increasing yearly, reaching 80 million vnd and 2,101 households, respectively, at the end of the fifth year (Fig. 6A,B). Another household type, such as the medium one, has its income stable at around 10 million vnd, while the household number increases by 155% after 5 years. The income of poor households is low and varies around zero. However, it is interesting that the number of poor households declines sharply to 740 from 3,500 households after 5 years. We can state that the farming system in which shrimp is dominant has strongly influenced the increase in rich households and the decline in poor households in commune 1. This balance in income distribution leads to an acceptable Gini value of 0.61 in this commune.

The number of rich and medium households increased rapidly in commune 2 after 5 years. It reached 1,384 and 109 households, whereas poor households declined sharply to 1,595 from 3,087 in the beginning (Fig. 7A,B). One special thing that happened in this commune was that the income of rich households reached a high of 226 million vnd, while that of the poor and landless was declining annually. This situation reflects an economic polarization, which is indicated by the value of the Gini coefficient (0.66) at the end of the fifth year.

Economic differentiation in both income and household number in commune 3 still occurs. However, the magnitude of income of the rich household is not much higher than that for the other household types (Fig. 8A,B). It reaches about 36 million vnd after 5 years. The number of poor households varies slightly in the early years, but remains at a high level afterward. Rich and medium households are a small number and they are stable in the commune. This commune's land has already been converted for both rice and shrimp farming; however, rice is the dominant crop because of the high proportion of high and medium land. In contrast, this area is far from a saline-water supply and shrimp is not favorable. A high proportion of the poor remained and the number of medium and rich households was unchanged. This was associated

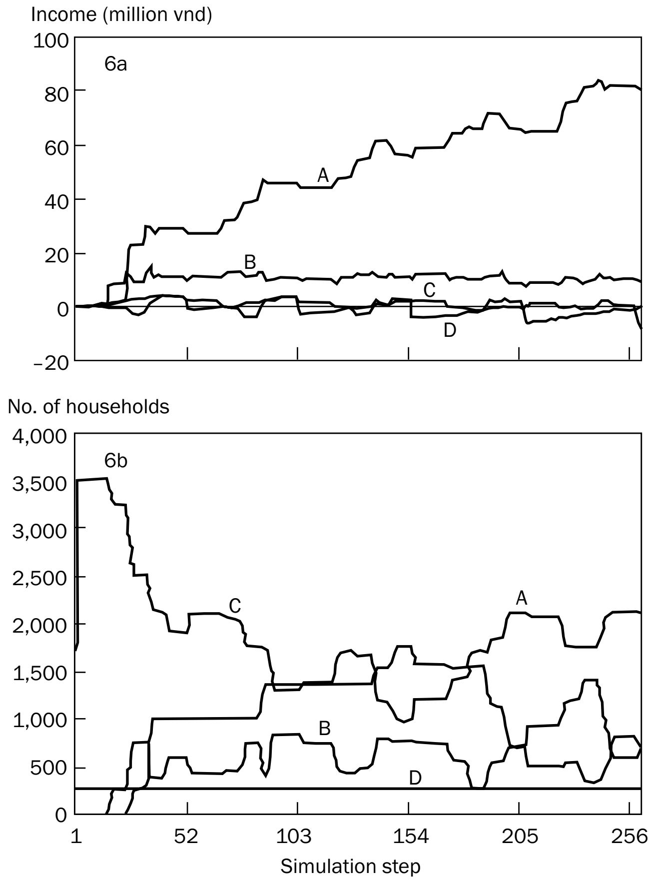

Fig. 6. Accumulated household income and number of households by class in commune 1 for 260 simulation steps. Panel a shows the averaged-accumulated income of rich households (A), medium households (B), poor households (C), and landless households (D). Panel b shows the total number of rich households (A), medium households (B), poor households (C), and landless households (D).

with their economic polarization, which led to a high Gini coefficient of 0.96 after 5 years of simulation.

Rice production is a dominant crop in commune 4, as was planned by the province. High and medium lands are occupied in a large proportion in this commune. A serious economic polarization is also found in this area. Rich households increase their income annually, reaching 40 million vnd, while that of medium and poor, together with landless households, declines yearly, to 12 million and –26 million vnd, respectively (Fig. 9A,B). More riskiness occurs for the poor and landless in this area. These poor and landless people have economic returns lower than their living costs. Because much economic differentiation occurred, the Gini value was 0.88.

A similar economic situation also occurs in commune 5; however, its variation in magnitude is much more obvious. Rich and medium households have incomes of 58 million and 14 million vnd in the fifth year, respectively. There is a similar trend

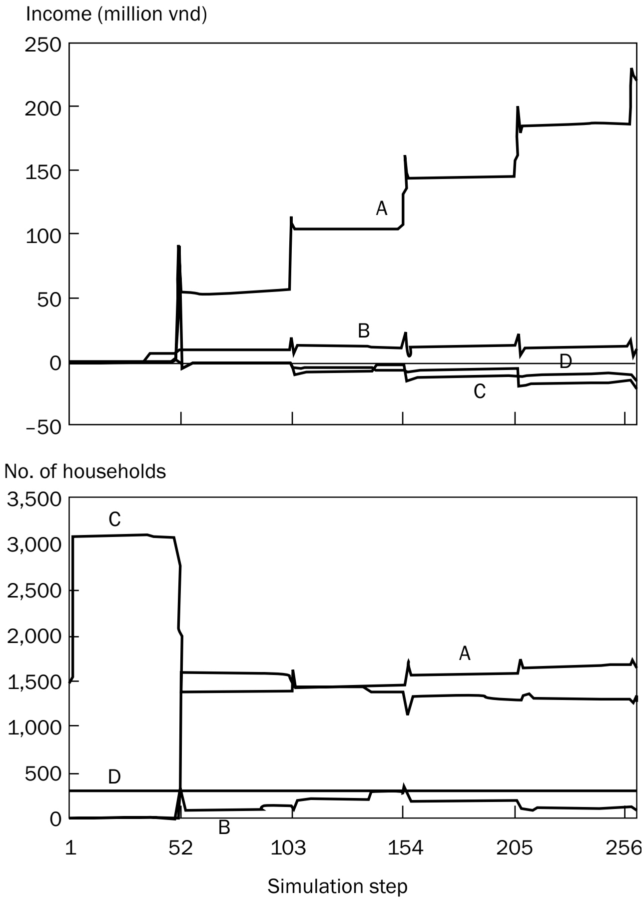

Fig. 7. Accumulated household income and number of households by class in commune 2 for 260 simulation steps. Panel a shows the averaged-accumulated income of rich households (A), medium households (B), poor households (C), and landless households (D). Panel b shows the total number of rich households (A), medium households (B), poor households (C), and landless households (D).

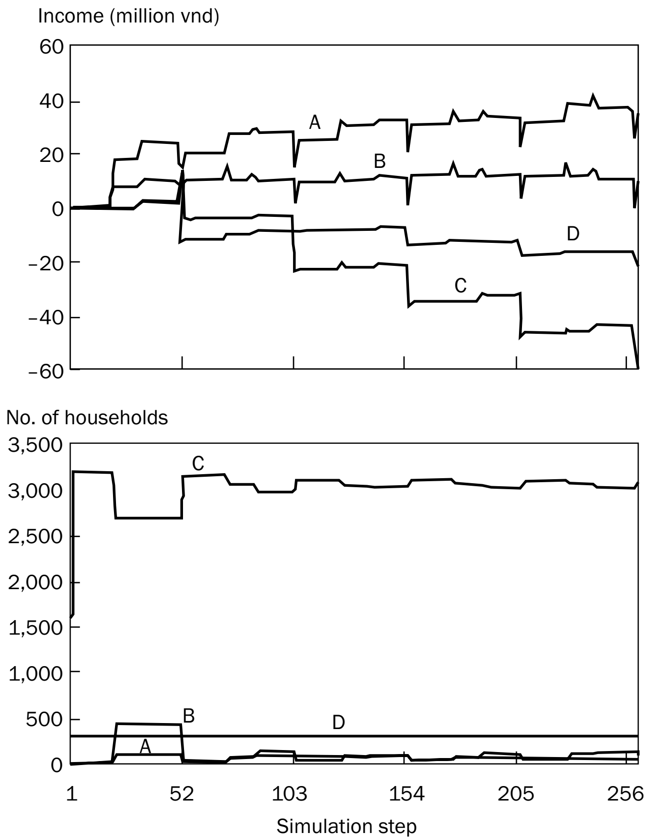

Fig. 8. Accumulated household income and number of households by class in commune 3 for 260 simulation steps. Panel a shows the averaged-accumulated income of rich households (A), medium households (B), poor households (C), and landless households (D). Panel b shows the total number of rich households (A), medium households (B), poor households (C), and landless households (D).

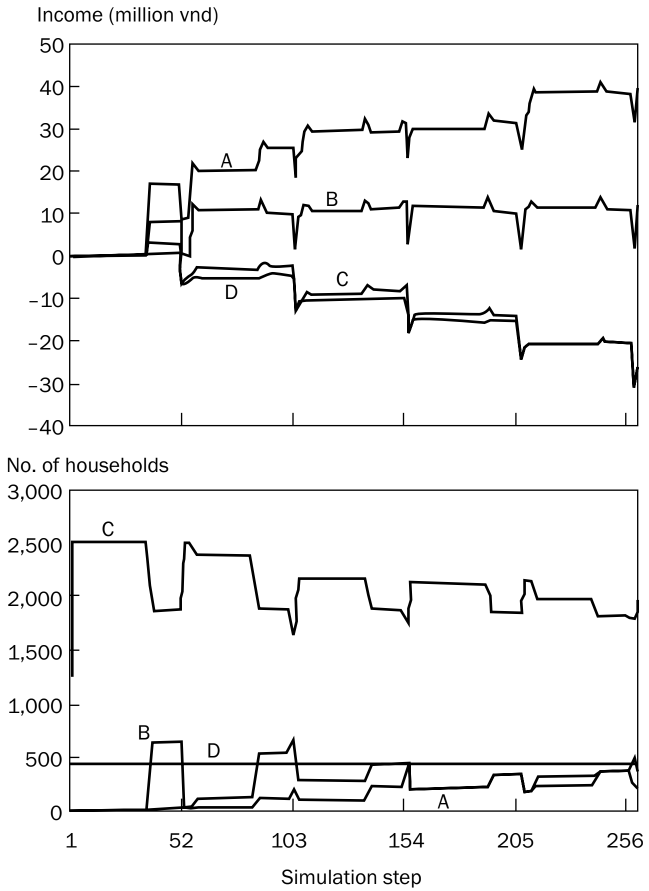

Fig. 9. Accumulated household income and number of households by class in commune 4 for 260 simulation steps. Panel a shows the averaged-accumulated income of rich households (A), medium households (B), poor households (C), and landless households (D). Panel b shows the total number of rich households (A), medium households (B), poor households (C), and landless households (D).

in variation in household income and number of households vis-à-vis commune 4; however, this took place much more clearly (Fig. 10A,B). Commune 5 is being noted as a favorable area for rice cultivation. A high economic differentiation is also recorded in this commune, reflected in the high value of the Gini coefficient (0.81).

Economic polarization is also found in commune 6; however, it is much milder than in communes 4 and 5. Income of rich households is 39 million vnd, while that of medium households is 11 million vnd. Poor households are less poor than in the other communes, only –7 million vnd in the fifth year (Fig. 11A,B). In addition, the number of poor households declines sharply and that of rich households increases rapidly. This leads to a Gini value of 0.65 at the end of the fifth year.

So, economic differentiation has occurred in every subzone. The number of rich households increased in all subzones except for subzones 3 and 4. The number of poor households declined in all subzones except for subzone 3. The gap in absolute household income in the subzone where shrimp farming is dominant is higher than that in the subzone where rice is dominant. The largest gap is found in subzone 2, which recorded 247.6 million vnd, and the smallest one is 30.8 million vnd in subzone 5. For economic differentiation, much more took place in subzones 3, 4, and 5, where the Gini coefficient surpassed 0.8. Although rice production dominated in these subzones, a high proportion of the poor remained, and a high Gini value was recorded. We can state that rice farming as the dominant crop would increase slightly the number of rich and medium households, but would barely reduce the poor in the community. In contrast, the number of rich households and their income would increase and the

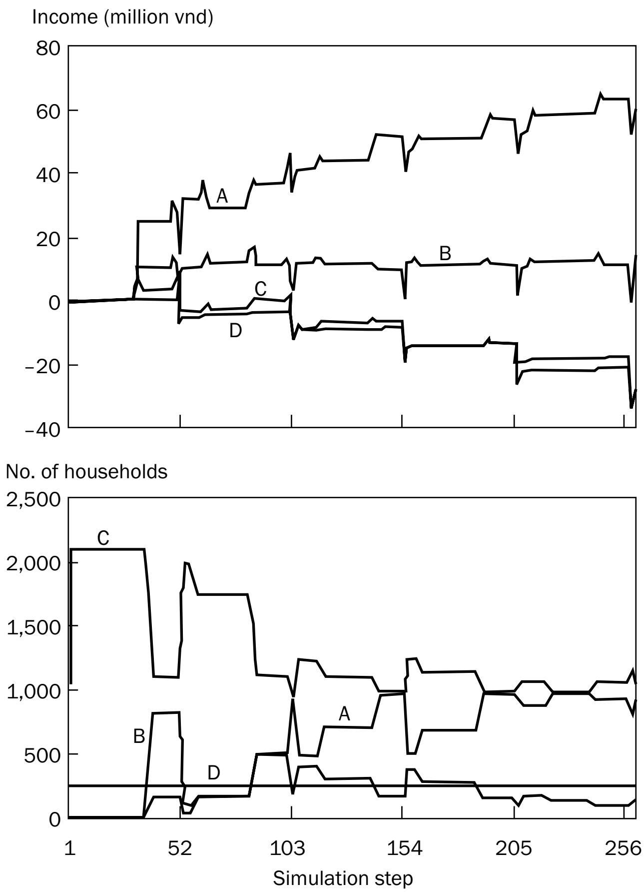

Fig. 10. Accumulated household income and number of households by class in commune 5 for 260 simulation steps. Panel a shows the averaged-accumulated income of rich households (A), medium households (B), poor households (C), and landless households (D). Panel b shows the total number of rich households (A), medium households (B), poor households (C), and landless households (D).

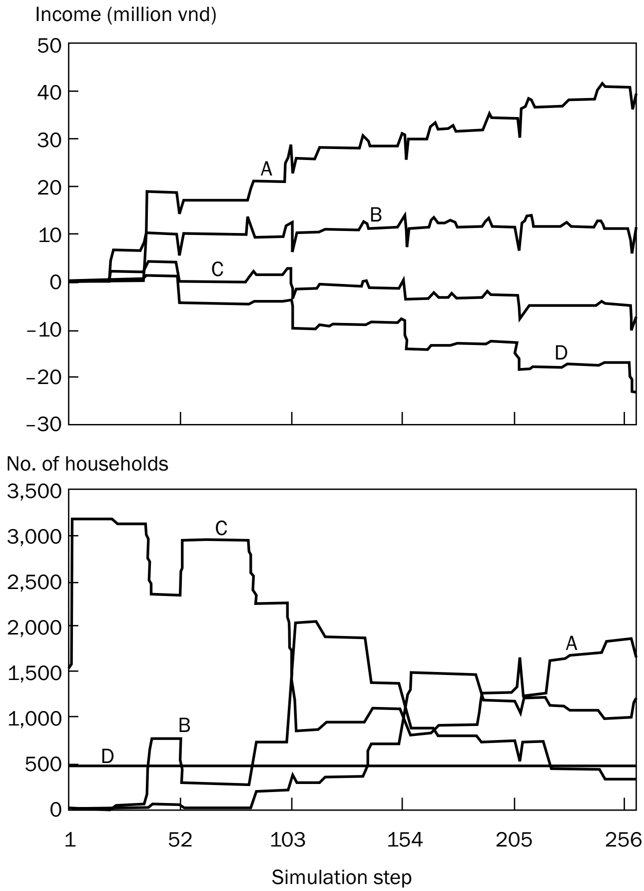

Fig. 11. Accumulated household income and number of households by class in commune 6 for 260 simulation steps. Panel a shows the averaged-accumulated income of rich households (A), medium households (B), poor households (C), and landless households (D). Panel b shows the total number of rich households (A), medium households (B), poor households (C), and landless households (D).

number and income of the poor would decline in the subzones where shrimp farming is dominant, such as in subzones 1 and 2.

In this step, we found that the simulation results are quite consistent with what happened in reality in terms of economic tendencies and a reduction in poor households while rich households increased in number in several communes.

Second model: dynamics of change and external driving forces

What has been run in the first model came from a static model. The model figured out the economic differentiation among and within subzones in the research area. The main weakness of the first model is that it simulates the present behavior of the stakeholders but does not take into account their potential decisions to change crops. The purpose of this second model is to simulate such capacity to change and to explore the reaction of farmers to contextual changes. Thus, the model that we propose here is more abstract than the previous one. It corresponds to stylized facts, although we introduce realistic data. In this model, the agent can choose three kinds of production: shrimp (2 crops per year), rice (2 crops per year), and shrimp and rice (1 crop of each). With this model, we will explore the influence of five kinds of factors: the price of the commodities, rice yield, shrimp yield, variation in prices, and network size.

Conceptualization of the model

The environment. The environment is composed of 300 plots of variable size (from 0.5 to 5 ha). There are three classes of soil (low, medium, and high) (see Fig. 12A). The environment is divided into two zones of equal size: one zone with fresh water (only rice can be grown) and one zone with brackish water (both shrimp and rice can be grown) (see Fig. 12B).

The farmer. We do not know in reality how farmers make their decision when they change crops. Thus, we have selected and adapted a theoretical model of choice, the Consumat model (Jager 2000). Developed by Jager and Janssen (Janssen and Jager 2001), this model is generic and seems relevant for the case study. This model assumes that an agent has four kinds of decision-making process:

- *Repetition.* The agent just keeps on rasing the same crop at time t + 1.
- *Imitation.* The agent imitates the decision of other agents he is connected with. In this model, the agent will adopt the decision made by the majority of his acquaintances (the agents he is connected with).
- *Deliberation.* The agent will compare the potential options and select one of those. In this model, the agent will choose the activity that has the best expected output. These expected outputs are given parameters that depend on the topology of the parcel. For rice, the expected yield is 5.5 t ha^{-1} for the high field, 4.5 t ha^{-1} for the medium-altitude field, and 3.5 t ha^{-1} for the low field. For shrimp, the expected output is, respectively, 100, 150, and 200 kg ha^{-1}.
- *Social comparison.* This is the same procedure as the imitation, but, before adopting a new activity, the agent checks whether the new activity has a better expected output than the current one.

In the Consumat model, these different modes of decisions are activated under different conditions. This depends mainly on two factors: the satisfaction of the agent (S) and his uncertainty (U). Each agent has a satisfaction threshold (St) and an uncertainty threshold (Ut). These thresholds are individual parameters. In the simulation, the St is randomly generated in the range of 0.6 to 1 and Ut is generated in the range of 0.5 to 0.95. The decision-making process depends on the value of the satisfaction and the uncertainty compared to the thresholds.

- If $S \geq St$ and $U < Ut$, repetition
- If $S < St$ and $U < Ut$, deliberation
- If $S \geq St$ and $U \geq Ut$, imitation
- If $S < St$ and $U \geq Ut$, social comparison

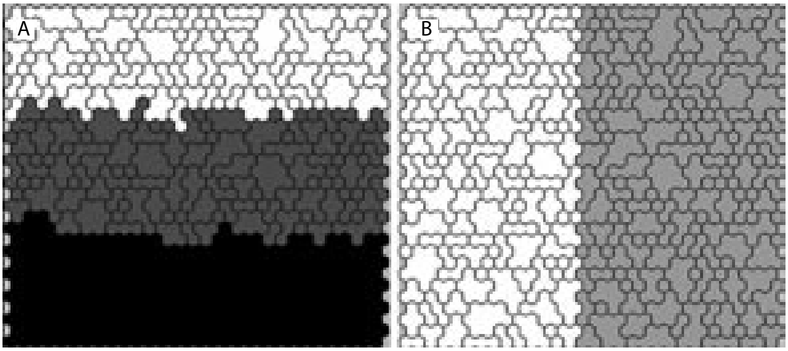

Fig. 12. (A, left) Three types of soils: low (black), medium (gray), high (white). (B, right) Two zones of water management: brackish water (white) and fresh water (gray).

For the Bac Lieu model, we decided to express the satisfaction of the agent as the ratio between the benefit and the cost:

Satisfaction = net income/costs.

Uncertainty depends on the difference between net income and expected net income:

Uncertainty = Min ((abs(net income – expected income)/expected income), 1).

In these simulations, the agents that are in the freshwater area cannot raise anything other than rice. What we measure is thus their willingness to change, their frustration. The agents in the brackish-water zone cannot raise two crops of rice.

Other objects. Two other objects are used in the simulation:

- *The market*. It stores the price of shrimp and price of rice, as well as the previous prices of shrimp and rice (which are used to compute expected income), and an attribute whose value is the variability range of the price. With each time-step, a new price is drawn in the range (price – variation, price + variation).
- *The crop*. It can be shrimp or rice. It has two attributes: yield and risk of failure. For shrimp cultivation, the risk of damage (probability that damage will occur) to the crops is set at 15% for lowland plots and at 30% for medium and highland plots. For rice cultivation, the risk of damage is set at 20% for lowland soil and at 5% for medium and highland plots. In case of damage, the quantity lost is variable and various scenarios will be simulated (see below).

The sequence diagram of this model is in Figure 13.

Scenarios

In these preliminary simulations, we test several scenarios to see the relative effects of different parameters. This corresponds to "what if?" simulations, leading to discussions on what would be the most sensitive factors to improve. Our observations are still on economic differentiation and net income. In these simulations, we explore the effects of various parameters that we grouped into four types of influences. For each scenario, we compare different values of parameters (low, medium, and high).

- *Influence of price*. We fix three different prices for rice (1,200, 1,500, and 1,800 vnd) and three different prices for shrimp (80,000, 100,000, and 120,000 vnd).

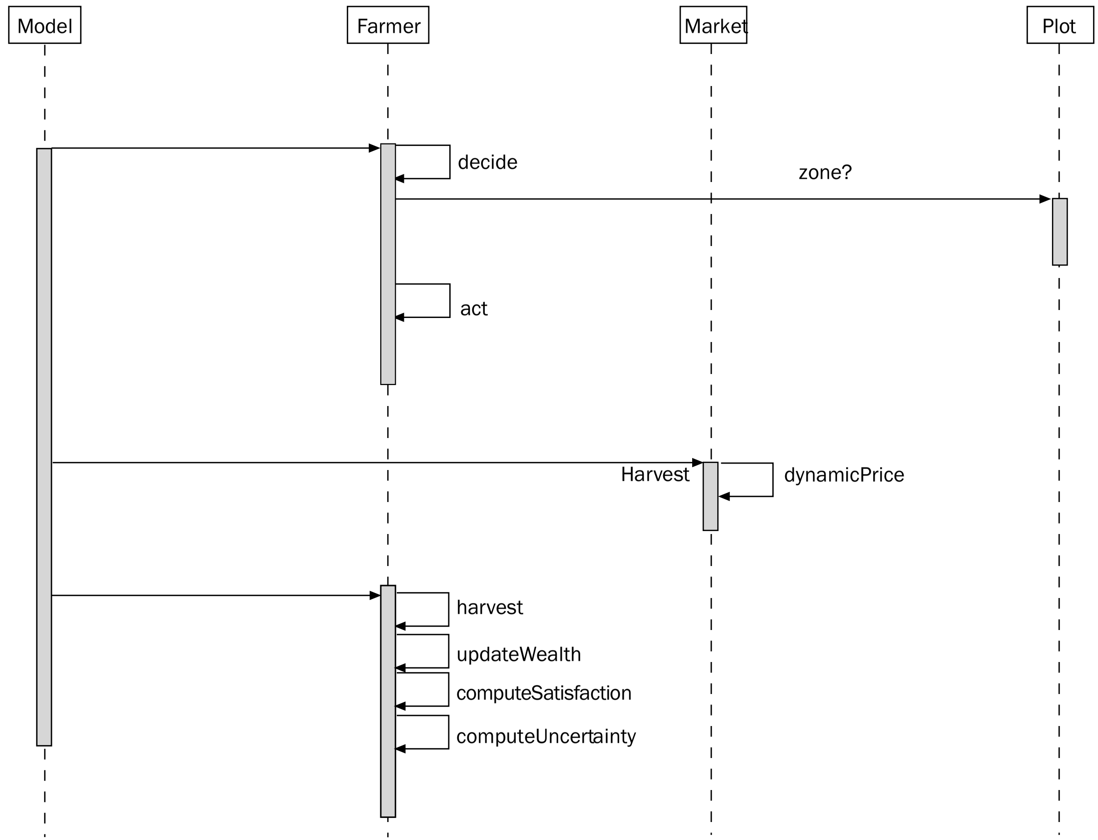

Fig. 13. The sequence diagram of the Consumat model.

- *Influence of rice yield.* Depending on the topology, yield is fixed at three alternative values: 3.5, 4.0, or 4.5 t ha^{-1} for lowland; 4.5, 5.0, or 5.5 t ha^{-1} for medium land; and 5.5, 6.0, or 6.5 t ha^{-1} for highland.
- *Influence of shrimp yield.* Depending on the topology, yield is fixed at three alternatives values: 200, 250, or 300 kg ha^{-1} for lowland; 150, 200, or 250 kg ha^{-1} for medium land; and 100, 150, or 200 kg ha^{-1} for highland.
- *Influence of risk.* Two dimensions are associated with risk: the variation in market prices (giving an interval around the average prices), which can have three values (0, 0.2, 0.4), and the amount of harvest lost in case of failure, which can also have three values for rice (0.2, 0.1, 0) and for shrimp (0.4, 0.2, 0).
- *Influence of the network.* The set of acquaintances of the agent is fixed as the neighbors of his plot, the agents in his hydraulic zone, or the full set of agents.

For a first exploration of the model, we have tested the influence of each of these parameters. The remaining parameters were set at their low value. For each simulation, the model is run in 30 time-steps representing 30 years. Each scenario is simulated 30 times and the values presented below are average values.

Results and discussion

For this preliminary exploration of the model, we have compared the different scenarios for economic differentiation, using the Gini coefficient, and the total wealth of the agents in the simulation. The results appear in Figures 14, 15, and 16.

Figure 14 presents the proportion of decision mode during the simulation. An interesting result is the fact that very few decisions are based on repetition, which means that the agents are not satisfied and certain. This illustrates the strength of this second model compared with the first one, which was based on the repetition of decisions every year.

The best results in Figures 15 and 16, in terms of aggregated wealth, correspond to the high and medium values of prices and high and medium values of shrimp yields. However, it appears also that these parameters also increase the economic differentiation among agents. The different rice yields do not affect the results of the simulations very much relative to the influence of prices and shrimp yields.

Another remarkable result is the effect of risk. The simulations with high risk give very bad results in terms of total wealth, even though prices can be good. More than the loss of harvest, high risk provokes frequent changes in activity linked to frequent failures. As agents are unsatisfied and uncertain, they engage in social comparison and deliberation. Thus, their choices are based on expected incomes that are highly dependent on market prices. These market prices fluctuate a lot among two time-steps. The simulation with high risks also shows a very small economic differentiation: most of the agents are poor.

In terms of economic differentiation, the best situation occurs with high risk because high risk makes everybody poor. The better scenarios are observed when agents are inserted into networks, from medium to large in size. The total wealth for these scenarios is not very good but we have to keep in mind that all parameters such as prices and yields were set at "low."

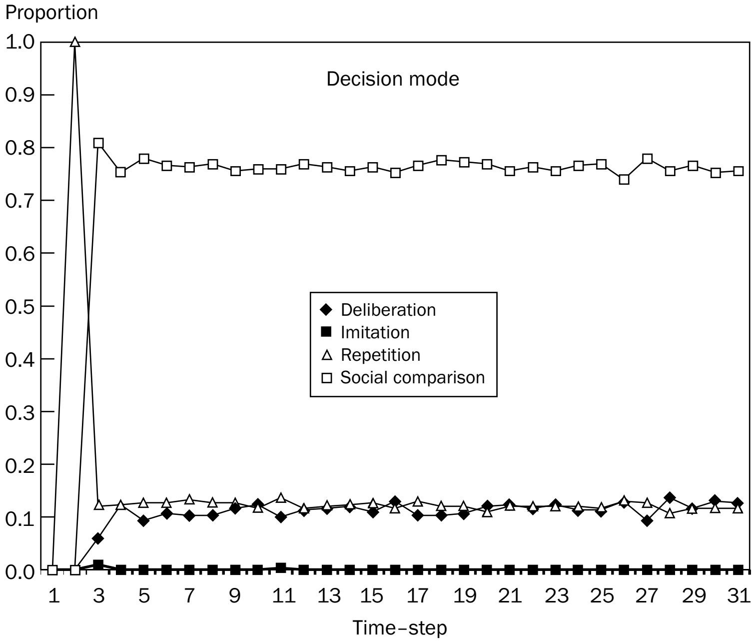

Fig. 14. The decision mode of the agents for one simulation.

These simulations correspond to a first exploration of the model. The first results can be presented, which lead to simple observations:

- The most efficient way to improve the wealth of the agents is to increase prices or increase the yield of shrimp production. But this also increases the economic differentiation. The increase in rice yield does not make a big difference in terms of wealth or economic differentiation.
- The reduction in risk of failure and variability of prices is very important to secure the decision of agents and avoid poverty.
- The exchange of information plays a role in reducing economic differentiation.

This second model gives interesting preliminary results. It shows how simulations can indicate to researchers and decision makers which factors make a difference and thus orient their research. The perspectives are twofold. First, we have introduced the Consumat decision-making model, which assumes a decision process of farmers. This has to be checked through some experiments. Second, the set of choices is very small (although realistic). The model could serve to study the introduction of innovations characterized by parameters such as price, yield, and riskiness and evaluate their chances of dissemination.

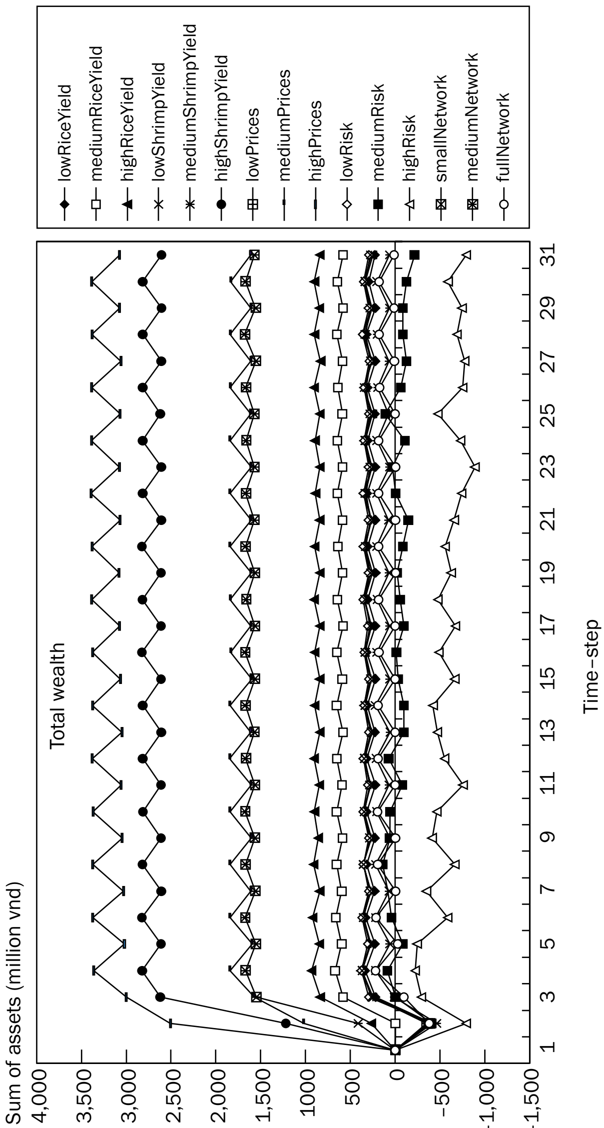

Fig. 15. The sum of individual wealth for various scenarios. The values correspond to the average value of 30 simulation runs.

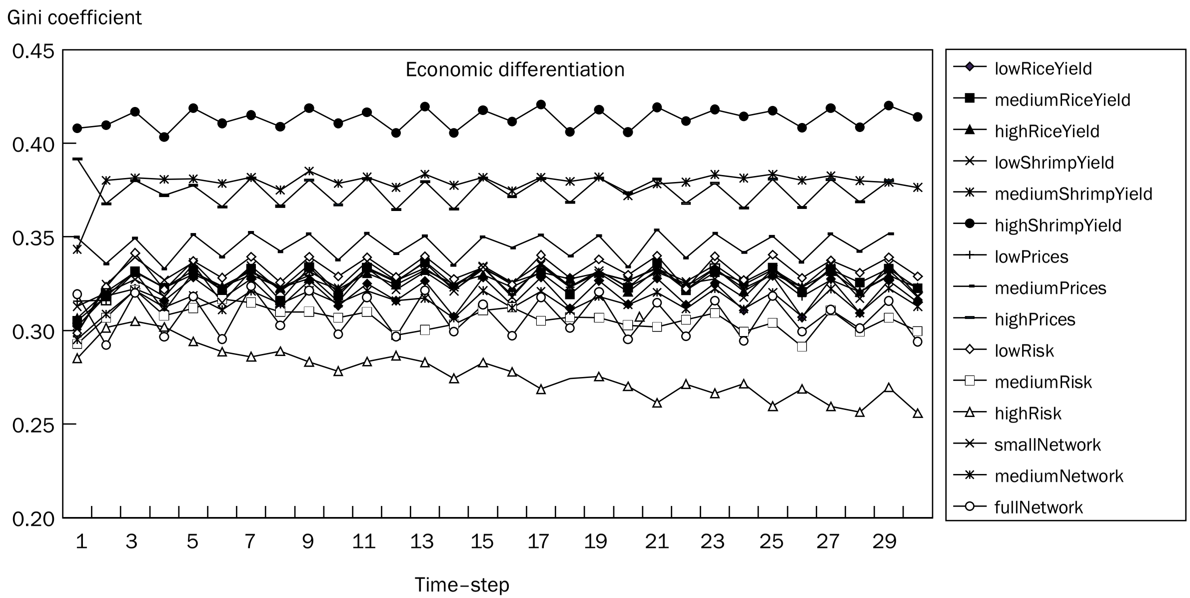

Fig. 16. Economic differentiation for various scenarios. The values correspond to the average value of 30 simulation runs.

Conclusions

We can draw several conclusions from the two models developed. From the first model, we conclude that

- The MAS concept associated with the CORMAS program has proved its usefulness in visualizing the diversified and complex farming systems at the study site of Bac Lieu in the Mekong Delta of Vietnam.
- Economic differentiation has occurred in every subzone at the study site in terms of both household average accumulation of income and number of households in the rich and poor class. As the best indicator of economic differentiation, the Gini coefficient had a low value in the first year. It increased, however, and became stable and had a high value from the second year onward in some subzones in either rice- or shrimp-based farming systems, especially in subzones 3, 4, and 5.
- The household average accumulation of income of the rich household class in those subzones where physical conditions allowed shrimp farming reaches a high value, while that of the medium and poor households remains at a low value, and is even negative for the poor in subzones 2 and 3.
- The household average accumulation of income of the rich household class in those subzones where physical conditions (freshwater zone) allowed only rice farming reaches a high value after 5 years of simulation, but this value is still less than that in shrimp-culture subzones. The poor households in these subzones of rice-based farming also face a negative income after some years.
- The number of rich households tends to increase over the years, whereas the number of poor households tends to decline from year to year of the simulation. However, the number of poor households remains high in subzones 3 and 4.

From the second model, which is more stylized, we can conclude that the economic wealth of the stakeholders mainly depends on the value of prices and yield of shrimp. These two factors are also responsible for economic differentiation. The exchange of information among stakeholders favors a reduction in economic differentiation.

References

Barreteau O, Bousquet F. 2000. SHADOC: a multi-agent model to tackle viability of irrigated systems. Ann. Oper. Res. 94:139-162.

Bousquet F, Bakam I, Proton H, Le Page C. 1998. Cormas: Common-Pool Resources and Multi-Agent Systems. Lecture Notes Artif. Intell. 1416:826-837.

Bousquet F, Barreteau O, Le Page C, Mullon C, Weber J. 1999. An environmental modelling approach: the use of multi-agent simulations. In: Blasco F, Weill A, editors. Advances in environmental and ecological modelling. Paris: Elsevier. p 113-122.

Brouwers L, Verhagen H, editors. 2003. Applying the Consumat model to flood management policies. Montpellier: SCS.

Deadman PJ, Schlager E, Gimblett R. 2000. Simulating common pool resource management experiments with adaptive agents employing alternate communication routines. J. Artif. Societ. Soc. Simul. 3. www.soc.surrey.ac.uk/JASSS/3/2.2.html.

Doran J. 2001. Intervening to achieve co-operative ecosystem management: towards an agent based model. J. Artif. Societ. Soc. Simul. 4. www.soc.surrey.ac.uk/JASSS/4/2/4.html.
Ferber J. 1999. Multi-agent systems: an introduction to distributed artificial intelligence. Reading, Mass. (USA): Addison-Wesley. 509 p.
Feuillette S, Bousquet F, Le Goulven P. 2003. SINUSE: a multi-agent model to negotiate water demand management on a free access water table. Environ. Model. Softw. 18:413-427.
Franchesquin N, Espinasse B, Serment J, editors. 2003. Coordination for contract realization in the hydraulic management of the Camargue. Montpellier: SCS.
Gallop K, Koopmanschap E, Barr J, Dung LC, Khiem NT. 2002. A framework for poverty-focused research and a baseline survey in the Quan Lo Phuong Hiep salinity protection scheme. DFID-CRF Project. University of Newcastle, International Rice Research Institute, Cantho University.
Gilbert N, Troitzsch K. 1999. Simulation for the social scientist. Open University Press.
Hoanh CT, Tuong TP, Kam SP, Phong ND, Ngoc NV, Lehmann E, editors. 2001. Using GIS-linked hydraulic model to manage conflicting demands on water quality for shrimp and rice production in the Mekong River Delta, Vietnam. Canberra (Australia): The Modelling and Simulation Society of Australia and New Zealand (MSSANZ), 1.
Holanda GM, Bazzan ALC, Gerolamo PB, Franco JHA, editors. 2003. Modeling the Bass diffusion process using an agent-based approach. Montpellier.
Hossain M, Ut TT, Khiem NT, editors. 2002. Impact of coastal embankments on farmer livelihoods: implications for policies. Bac Lieu (Vietnam).
Jager W. 2000. Modelling consumer behaviour. Groningen (The Netherlands): Universal Press. 225 p.
Janssen M, Jager W. 2001. Fashions, habits and changing preferences: simulations of psychological factors affecting market dynamics. J. Econ. Psychol. 22:745-772.
Janssen M, editor. 2003. Complexity and ecosystem management: the theory and practice of multi-agent approaches. Chettenham (UK): Edward Elgar Publishers.
Mathevet R, Bousquet F, Le Page C, Antona M. 2003. Agent-based simulations of interactions between duck population, farming decisions and leasing of hunting rights in the Camargue (Southern France). Ecol. Model. 165:107-126.
Rouchier J, O'Connor M, Bousquet F. 2001. The creation of a reputation in an artificial society organised by a gift system. J. Artif. Societ. Soc. Simul. 4. www.soc.surrey.ac.uk/JASSS/4/2/8.html.

Notes

Authors' addresses: L.C. Dung, N.N.G. Vinh, and L.A. Tuan, Cantho University, Cantho, Vietnam, email: lcdung@ctu.edu.vn; F. Bousquet, CIRAD, Bangkok, Thailand.