Tradition and Change in the Southern Cone of America

Limits and potentialities of Multi-Agent Systems as methodological tools for the study of the social impacts of territorial dynamics[1]

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Abstract

The territorial transformations that have taken place during the last decade in the South American temperate grasslands – the "Pampas" - have been accompanied by dramatic social changes. As large-scale agribusiness replaces extensive livestock production, agricultural investment fund managers –IFM- break as the newest actors of the reshaped landscape. Unable to reproduce their traditional livelihoods under the growing economic and environmental pressures, many family farmers are selling or renting their properties to IFM while migrating to the cities. Uruguay is a privileged laboratory for the study of this coupled socio-territorial dynamics. As in Argentina and Brazil, Uruguayan Pampas' are being agriculturized[2] by large-scale soybean mono cropping. This process is being accelerated by the emergence of the new markets of China and India, the two main soybean importers of the Pampean countries. Bounded by tradition and by values that go beyond profit making, some family livestock farmers strive to avoid rural exodus and to adapt to these new scenarios while maintaining their livelihoods, strongly identified with extensive cattle grazing. Small to medium-sized farmers usually choose between two adaptation strategies: i) to continue with cattle grazing through, a) technological innovation and intensification and/or b) cost reduction; or ii) to abandon livestock production and convert to soybean production. Any of these strategies are threatened, however, by the strong increase of land prices, generated not only by soybean mono cropping (dubbed the "white gold" of South America), but also by major forestry and pulp mill developments. This paper will not focus on the environmental impact of soybean mono cropping in the Pampa biome, an issue which is still highly disputed. It will, instead, offer an interdisciplinar, systemic approach to the social consequences of the land competition between modern, large-scale agriculture and traditional, low input livestock production. How do land concentration and large-scale mono cropping affect the social sustainability[3] of extensive livestock farming systems operating in usually small production units? Is it possible to model – and simulate – simultaneously the dynamics of physical-biological systems interacting with social systems? This article aims at evaluating the interest, contributions and limits of multiple-agent-

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[2] "Agriculturization" is the permanent substitution of agriculture for the crop-livestock rotation, which was the dominant farming system used in Uruguay until the mid-1970s.

[3] "Social Sustainability" can be defined as the capacity of communities or groups of maintaining certain population and a given standard of living for a long time, enduring stress due to external changes in the political, economic and environmental contexts. It addresses social structures and living conditions of human populations, acknowledging the fundamental role that social actors, social capital, organization and institutions. Because of this, this approach to sustainability focuses not only on the relationships between the physical environment and societies, but also on the cultural values, perceptions and interests of the different social groups in relation to the environment. Its study implies to consider a society in its space-time matrix, and to address the mechanisms through which that society remains in place in the long-term (Adamo, 2003).

based simulations or Multi-Agent Systems (MAS) as a methodology to answer to these questions. The underlying hypothesis is that MAS contribute to improve the understanding of the decision-making processes of family farmers, who must decide between sticking to traditional cattle-breeding or investing in the higher and shorter-term profitability of soybean production. However, MAS models must be enhanced through the inclusion of socio (and even psychological) variables allowing to better understand the complex dynamics of land – use related decision making processes. The article's structure has five sections: i) brief introduction of MAS, ii) application of MAS simulations (DinamicaParcelaria) to the specific case of territorial transformations resulting from the dialectic monocropping / livestock family farming in the Uruguayan Pampas, iii) application of MAS simulations (Arapey) to a case study in Northern Uruguay, where the traditional extensive livestock production system has not changed in the last two centuries, remaining as the sole production system iv) crosschecking of the above-mentioned preliminary results with the outcomes of participatory meetings with livestock producers in Uruguay.

Key words: multi-agent systems, land use change, South-American grasslands, social sustainability, gaucho culture.

1. INTRODUCCION

Social and territorial transformations linked to agro-eco-systems have been traditionally studied at the macro level and through single economic or productive approaches, based on the actors' "economic rationality" and profit-maximization goals. However, complex situations such as the coupled evolution of social and ecological systems could be better understood if studied from a systemic and interdisciplinary perspective.

The central idea of systemic approaches is that complex situations can be represented as a set of components interacting in a way that makes it difficult to foresee their future evolution (Simon, 1986). When future evolutions are difficult to foresee, systems approaches become necessary. In systems approaches, human beings are considered system drivers or pilots (Landais and Bonnemaire, 1994).

A second idea, also strongly linked to the systemic approach, is that complex systems are not determined by the environment but are autonomous. Complex systems are characterized by their capacity to inform themselves about the state of the environment and to use that information to adjust their functioning. As Morin (1990) states, the concept of autonomy reconciles the apparent dichotomy between general laws (such as economic laws, which are valid at several levels) and the diverse individual trajectories observed at the micro level.

According to Anderies (2002) what is usually studied about systems is related to the macro level (dynamics of species' populations, unemployment, national gross products or income distribution). However, our approach focuses on the micro level through the study of individual behaviours and local interactions. The challenge is to transform this local-level understanding into a global understanding (Schelling 2006 ;Beinhocker 2006).

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The evident difficulties to achieve this goal are compensated by the utility of such an approach: it contributes to the anticipation of the impact of public policies and the farmers' reactions *vis a vis* new regulations and incentives (Deffuant et al. 2002, Balmann et al 2002). It also facilitates the understanding of the global qualities of a system, such as the difference among average production units' sizes in regions that seem to be, at least at first sight, similar (McAllister et al. 2005).

Almost all social science research proceeds by building simplified representations of social phenomena. Sometimes these representations are purely verbal. For example, the traditional work of historical scholarship is a book-length representation of past events, abstracted and simplified to emphasise some events and some inter-relationships at the expense of others. The difficulty with such verbal presentations is that it is hard for the researcher and the reader to determine precisely the implications of the ideas being put forward. Are there inconsistencies between the various concepts and relationships? Can they be generalised and if so, what inferences can one make? In other fields, for example, some areas of economics, the representation is usually much more formal and often expressed in terms of statistical or mathematical equations. These make assessing consistency and generalisability and other desirable properties much easier than with verbal representations. In these areas, it is generally accepted that understanding the social world involves model-building. However, statistical and mathematical models also have some disadvantages. Prime among these is that many of the equations which one would like to use to represent real social phenomena are simply too complicated to be analytically tractable. This is particularly likely when the phenomena being modelled involve non-linear relationships, and yet these are pervasive in the social world. The advantages of mathematical formalization thus evaporate. A common solution is to make simplifying assumptions until the equations do become solvable. Unfortunately, these assumptions are often implausible and the resulting theories can be seriously misleading. This is the criticism often put before economists who make assumptions such as the availability of perfect information, perfect rationality and so on, not because they believe the economic world really does have these characteristics, but because otherwise their models cannot be analysed. (Simon,1986, Gilbert and Terna, 1999, Gilbert, 2008, and Epstein, 2006).

Models are abstractions of reality. Their purpose is to enhance our understanding of complex systems and to facilitate our intervention on them. Good models foster the rise of new questions and interpretations, feed debates and highlight variables that had been previously ignored (Carpenter et al. 2002). Complexity implies that the unforeseeable is possible (Le Moigne,1994). Simulations are, in consequence, only tools to explore the unforeseeable consequences of each new model, and cannot be seen as predictors.

Even when certain models are able to reproduce with high precision what has happened in the past, it is impossible to assure that its chosen components or dynamics will continue to be the same in the future. Surprises may arise at any moment. "Good" models offer enriched representations of possible options and the opportunity to explore the consequences of possible interventions (Legay 1997, Holling et al. 2002, Checkland 1999).

2. MODELLING AND MULTI-AGENT SYSTEMS (MAS)

Agro-eco-systems can be seen as complex systems since they integrate multiple components interacting in many different ways. They include physical, biological and social systems, each of which has their own dynamics and interdependencies. Multi-Agent Systems (MAS) have been proposed as tools to study agro-eco-systems with some interesting results. Bousquet et al. (1999) show, for instance, that the simulation of the strategies employed by African herdsmen are useful to understand the impact of the construction of water points in desert areas. Walker (2002) has proved the interest of agent-based simulations to model and simulate the learning process of livestock farmers in Australia and to anticipate the impact of public policies on livestock production and its environmental and social consequences.

In France, the International Centre of Agricultural Research for Development (CIRAD) has created a simulation platform called "Cormas" (Bousquet et al 1998). It is used to simulate land cover changes in a region affected by different production strategies at the herd-herdsman level. It has also contributed to the elaboration of collective action proposals for the sustainable development of the region (Bousquet et al. 2002).

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The big challenge resides in modelling – and simulating – simultaneously the dynamics and interactions of physical-biological systems and social systems. The evolution of physical-biological systems is influenced by the dynamics of the social system with which it interacts, and vice versa. Many studies (Lambin et al Panarchy) have shown that ecological and agricultural studies cannot be studied as independent disciplines. This has led to the new concept of "agro-eco-systems" with different aggregation levels (parcels, production units, regions, etc.). In any case, this new approach implies the consolidation of models of different natures (Landais & Bonnemaire 1994; Beinhocker 2006):

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1. Models of biotechnical nature. They represent different performances according to the practices used on the field. They can also describe "ecologic" impacts.

2. Models of psycho-socio-cognitive nature: their objective is to describe management and system-organization decision-making processes.

Many of the phenomena faced by researchers take place at scales at which physical experiments are not feasible. In these cases, it is difficult to identify their relevant variables and, when found, they cannot always be expressed quantitatively (Edward-Jones and Murray 1994). In order to contribute to overcome those limitations, MAS (Janssen 2002) have evolved from the field of Distributed Artificial Intelligence and use Object-Oriented Programming. In MAS models, agents change their actions following the result of their interaction. The overall system result depends on those interactions and, as Bonabeau and Meyer (2001) verify, a slight change in the dynamic of one of its components might result in significant variations in the global functioning of the system.

Modelling constitutes an important step towards the improvement of our understanding of the functioning of complex systems and our anticipation of their future evolutions. It also generates coherent information out of diverse sources. Following Carlson et al. (1993) if data collection is not accompanied by the necessary reflection to make them coherent, the result is big amounts of data and poverty of understanding. "Drown in data and starving for knowledge", Wilson states (1999). The volume and complexity of data, along with the need to reach a shared vision able to foster collective action (Simon 1991), make of modelling a must, and not an option (Malézieux et al. 2001).

We do not intend, of course, to model reality, partly because that would be useless, partly because it would be impossible. The same system can be described in several ways, all equally valid. Legay (1997) proposes that those descriptions be called "models" when their components, dynamics and interactions have been defined. We define simulation as the computer implementation of a model that allows for exploring its evolution as well as proving the coherence and consistency of its construction. In order to simulate a model where bio-physical and social subsystems interact, the model should:

1. Take into account the dynamic present in decision-making. For that it should incorporate qualitative information in the form of decision rules;
2. Show the dynamic of this interaction, and
3. Include heterogeneous components with quantitative and qualitative dynamics.

We propose Unified Modelling Language (UML), OMG (2003); Le Page and Bommel (2004) as a tool to reach the above-mentioned requirements. By using diagrams – simple and unambiguous – UML facilitates a shared understanding of the described situation. It also facilitates the quick, easy use of that information (Larkin and Simon 1987). Fowler (2004) describes eight dynamic UML diagrams and six static UML diagrams. Marshall (2000) and Eriksson and Penker (2000) develop proposals for the use of those diagrams in organizational management.

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Once the system has been modelled, the researcher – and other stakeholders - can perform mental experiments to anticipate its evolution. Computer simulations allow performing virtual experiments through modelling by showing the precise consequences of the model's structure and dynamics. This possibility contributes to widen the researcher's capacity to reflect upon what he or she already knows and to discover consequences that had been unseen up to the moment (Simon 1991). MAS are the best prospective tool to study heterogeneous agents such as farmers, ecologists, technicians, the climate, the market and institutions, all of which are affected by their spatial localization and all interacting in a non-equilibrium situation (Janssen 2002; Parker et al; Bousquet 2006).

In agro-eco-systems, technical-led productivity increases usually take place in regions that are rich in natural resources, as is the case of large areas of South America. But the same continent also hosts large extensions of land with variable, heterogeneous resources, equivalent to "rangelands" as defined by Stuth and Lyon (1993), which are grazed with no previous cultivation and that we will call "natural grasslands" or unimproved native pastures. The common trend among those regions is the rising productivity of human labour (Landais and Balent, 1993). Though this kind of marginal regions have a minor impact on agri-business, it represents around 50% of the emerged land (Lambin and Geist, 2006, Nolan et al. 2000). This makes its study unavoidable, both at the local and at the global levels. We have modelled and simulates both rich and marginal production regions of the South American cone with MAS. This paper aims at summarizing those multi-agent simulations and to analyse the interest, contributions and limits of MAS as a methodology to study the evolution of family farming systems at different scales and periods (space-time matrix). The analysis will be based on the crosschecking of model results with the outcomes of direct observation and in-depth interviews in the selected areas of Uruguay.

3. THE CONTEXT OF THE SOUTHERN CONE

In extensive areas of Uruguay, Argentina and Brazil temperate grasslands or Pampas, livestock production takes place in natural, non-cultivated grasslands, usually named "campos". Livestock production in those countries generates not only high levels of exports but also industrial activities and new employments linked to the sector. Last, but not least, there is a strong cultural identity linked to cattle-breeding. This cultural trait is usually identified with the "gaucho" tradition.

All this generates important challenges to South American livestock producers, whose activities have become the centre of global attention, specially in some ecologically vulnerable areas such as the Amazonia. From an economic point of view, livestock productivity has been increased through intensification and capital investment. Traditional cattle-ranching with low input and extensive grazing in natural prairies is widely seen as unproductive, at least, when considered from a mercantilist point of view.

The recently observed changes in the agrarian system of the Rio de la Plata Basin (coinciding with the administrative borders of the Common Market of the South, or "Mercosur", in South America), share important similarities across regions. The economic, environmental and social consequences of those agro-ecologic dynamics, driven by the explosive introduction of soybean crops and a new push of the forest industry, should be better analysed. The raise of soybean production, led by the increased consumer demand from the Chinese and Indian emerging markets, is common to all countries in Rio de la Plata Basin. Mainly produced by large, international companies, it has had the effect of increasing the rent value, and therefore the values of properties that could put pressure on traditional cattle producers to incorporate more intensive technologies. The resulting evolution of the farming structures has lead to a new kind of actor, the agricultural investment fund managers -IFM from now on- that rent great extensions of land.

The arrival of IFM makes researchers and governments wonder about the social sustainability of family farmers traditionally devoted to extensive cattle-breeding. Questions are being raised about the capacity of livestock production communities in Uruguay (but also in Argentina and Brazil) to be "socially sustainable" or to maintain their population and a given standard of living for a long time, enduring stress due to external changes in the political, economic and environmental contexts led by the unregulated soybean boom (Adamo, 2003).

The soybean expansion process takes over not only new lands traditionally devoted to extensive livestock production but also the cultural values, perceptions and interests of the gaucho producers and their families, which have coexisted in relative harmony with the environment for 200 years (Litre et al., 2007). Uruguay – chosen as our case study of our MAS simulations - has a total area of 17.6 million hectares with 15.3 million hectares (87 percent) devoted to cattle, sheep and cropping. Despite the total land area being only two thirds the size of New Zealand, Uruguay's farmed area is greater due to the very high level of utilisable land and lower area in forest. The landscape is mostly flat to gently rolling, rising to a highest point of 513 metres.

Extensive cattle and sheep grazing is the main farming activity and most of the grazing land is unimproved native pasture, amounting to 11.7 million hectares. There is a huge potential for development with cultivation and the introduction of new grasses. There are an estimated 11.7 million cattle and 9.7 million sheep in Uruguay. While cattle numbers in Uruguay have been rising gradually the national sheep flock has been trending down rapidly from around 25 million in 1990 in response to the reduced demand for wool.

The latest General Farming Census census of Uruguay, dating from 2000, showed that the country has approximately 32,000 livestock farms. Of these farms the 9 percent that are over 1,250 hectares carry 51 percent of the stock. Once a major supplier of beef to world markets, the Uruguayan livestock industry has until recently stagnated. Over the last five years there has been upward pressure on land prices due to land competition. This has arisen mainly from investment by neighbouring Argentinean investors for crops such as soybeans, and major forestry and pulp mill developments, mostly close to the border in the west. More recently, government incentives in Brazil aimed at increasing production of ethanol and bio diesel from crops have driven grain and beef production into non-traditional areas, adding further pressure.

The soybean boom in the Pampas is the result of at least two factors: economically, the rise of the new markets of China and India, which are importing increasing amounts of the crop to satisfy their new middle-class consumption demands. Politically, the almost complete lack of development-oriented regulations from the government (Arbeletche & Carballo, 2007) fosters the arrival of international corporations which land in the Pampas attracted by the liberalization and the stability of the Uruguayan market. From 2000 to 2006, the total agricultural area in Uruguay increased in 17% due to the expansion of soybean crops which have multiplied by 25-fold (in area). Among soybean producers, 6% have control of 40% of the sowed area; while among the whole agricultural area, 1% of the producers have control of 45% of the sowed area.

The consequences of large-scale soybean monocropping in Uruguay include a massive exodus from the countryside as family farmers[4] found they could no longer make a living or were driven off their land. Between 1990 and 2005, the number of Uruguayan farmers owning properties of 50 to 100 hectares and cultivating soybean have decreased from 733 to 242. At the same time, producers having 1000 or more hectares in this activity have trippled, from 23 in 1990 to 87 in 2005 in the same period (Arbeletche & Carballo, 2007). The official cattle inventory in Uruguay confirms the numbers: Uruguay's cattle herd as of June 30, 2006 totalled 11.71 million head. This was 2.1 percent lower than 2005. The total cow inventory was 2.3 percent less than a year ago, amounting to 4.47 million head. The number of breeding cows was down 2.4 percent from 2005, totalling 4.05 million head.

The soybean boom is accompanied by a raising economic concentration, which affects thousands of producers, especially family farmers cultivating soybean: in just 5 years, 45% of them have rented or sold their land and abandoned the activity. (Arbeletche et al, 2006) The soybean boom is also characterized by the denationalization of the agricultural production and the arrival of monopolistic input suppliers (especially of seed and technologies driven by a few foreign companies). Also, aspects such as biodiversity, soil fertility conservation and, in general, the capacity of ecosystems to satisfy human needs are all related to land use changes, and therefore, deeply linked to economic or socio-political disturbances (Paruelo et al. 2006).

In order to understand and predict how land use change affects the environment, historical reconstructions should be made in order to identify the essential factors and to develop models that help exploring future scenarios. These models should show these dynamics at different levels, including the global scale (Lambin et al. 2006).

The dramatic social and territorial transformations originated by these unprecedented changes require the design of creative policies that could leverage the positive aspects of land use change and mitigate the negative ones. Though focused on Uruguayan natural grasslands, the following models constitute a methodology that can be adjusted and reproduced in similar circumstances, or in comparison to other regions of the Rio de la Plata Basin (especially those sharing the Pampa biome – Argentina and Southern Brazil).

4. THE MODELS

4.1. DINAMICAPARCELARIA

The first model analyzed here is *DinamicaParcelaria* (Corral et al. 2007; Arbeletche et al. 2007). This approach focuses on possible land tenure and land use evolutions (on lands that are perfectly suitable for cropping) as well as on the evolution of different kinds of producers, including family farmers. This approach's validity has been tested through the construction of a typology of producers' behaviours and the resulting organizational structure of their production units, among others research projects.

The first step when modelling land use and production units evolutions is to establish a general characterization of the agrarian dynamics of the studied region. This characterization was

[4] The concept of "family farmers" differs from the notion of "small farmers": while the criteria for identifying a small producer is the production unit's surface, family farming sets surfaces aside and stresses the importance of labour and the "who does what". If the producer and his or her family itself perform most of tasks, the farmer Hill is defined as family farmer (Litre et al. 2007).

created out of secondary information (specially national and international statistics) and from other documents that allow comparisons with other regions as well as with different types of historical data.

The chosen typology was based on the General Farming Census (year 2000) and the farming polls (years 2002 to 2005) of the Economic Research head office of the Livestock, Agriculture and Fishing Ministry of Uruguay (Arbeletche et al. 2006). The classification was done using the Cluster Analysis methods from the (Sparks) algorithms contained in the SPSS software (version 10).

The DinamicaParcelaria methodology consists of three stages:

Stage I: Conformation of a multidisciplinary team integrated by researchers, university teachers and extension agents from Uruguay, Argentina and France.

Stage II: Model construction through UML (Fowler 2003). As previously stated, “model” is understood as the construction of an image that highlights those aspects that are of interest of the modellers, ruling out others)

Stage III: Simulation. We define simulation as the computer implementation of a model that allows to exploring its evolution as well as to proving the coherence and consistency of the model’s construction (Zeigler et al., 2000). It was done using the Cormas platform (Bousquet 1998)

4.1.2 DESCRIPTION OF THE MULTI-AGENT MODEL

The resulting model shows the interactions generated through land use choices (agriculture and cattle-breeding) and land ownership (rented or owned). The model aims at generating knowledge about these two options and at understanding the relationship among traditional producers and the new actors represented by the Investment Fund Managers (IFMs). IFMs’ strategy consists of renting land (plots) in order to intensively and continuously produce soybean crops. The model also considers that traditional farmers (including small, medium and big) who have a history of combining livestock and crops, are profit-sensitive, and that they apply norms originated from their experience –rules of thumb - considered adequate for the situation.

The model simulates the behaviour of both, traditional livestock producers and IFMs and assumes that the three types of traditional producers (small, medium and big) behave in the same way (by sharing rules) though they manage different amounts of resources (number of plots they own and/or operate). Therefore, traditional producers risk their production units, while IFMs manage funds (other people’s money).

In DinamicaParcelaria, IFMs rent (and eventually release) plots as long as traditional producers are willing to offer some of their plots for rental (and eventually recover them). This means that the initiative of whether to rent or not is taken by traditional producers according to their decision-making rules, represented by a UML Activity Diagram (see Fig. XX).

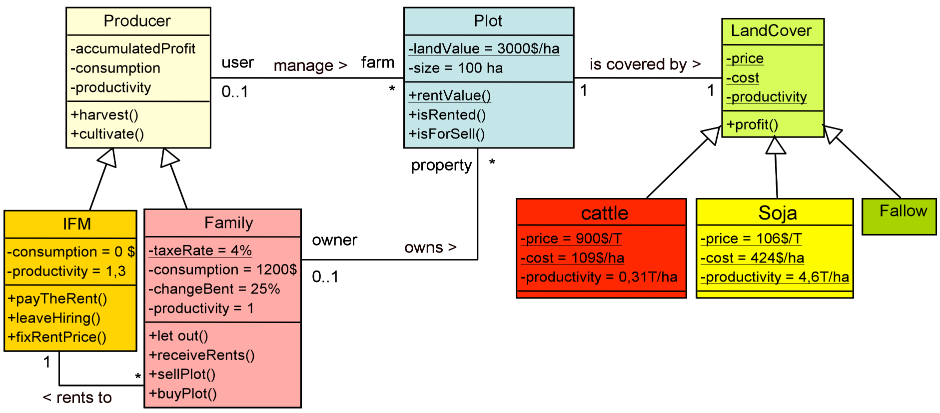

Figure 1: UML class diagram showing the structure of the model.

The main assumptions of the model are as follows:

- Traditional farmers can offer one or more of their plots for rental,
- They can only offer their plots for rental to IFMs,

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- The rented plots are always used for continuing cropping (the only activity of IFMs) from the very moment they are rented.
- Traditional producers can buy and sell plots among themselves (from traditional producer to traditional producer), as well as rent their plots to IFMs, which can only rent plots to traditional producers (in this model IFMs cannot buy land).

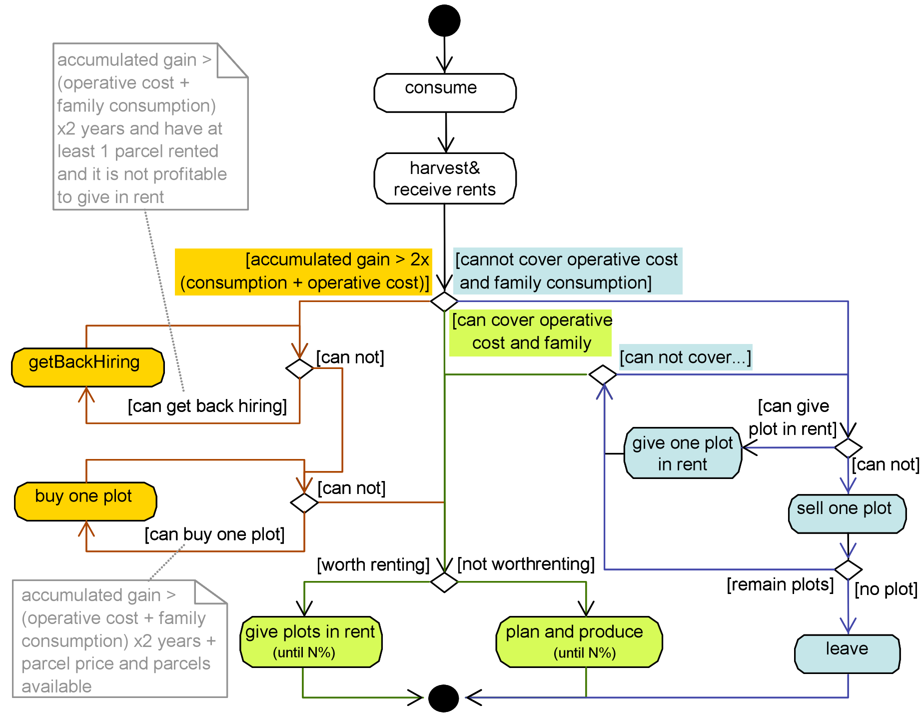

Figure 2: UML activity diagram showing the main step of a family

SIMULATION

The last two tasks of the Activity Diagram relate to the planning of the next year: the current version of the model looks for the most profitable activity (renting, cattle-breeding or continuing soybean cropping) taking the gross margin (production * price - cost) as the point of departure. After identifying the best alternative, the simulation goes through all the plots of the traditional producer and each plot is given 25% of chances to change to the best alternative (this percentage was defined as the predisposition to change).

It is worth to note that if a certain activity appears systematically as the best alternative, then traditional producers will tend to move towards this activity, year after year, since each year they will change up to 25% of each of their plots to this alternative. Rented plots should be given special attention since the traditional producer cannot change the use of these plots while they are being managed by IFMs.

Regarding land use, the simulation graphically shows the type of use given to each plot at each time step (year). The different use options are: i) continuing soybean cropping, ii) cattle-breeding, iii) empty or rented. A plot will be empty from the very moment it is returned to its owner (when the IFM no longer rents it). Eventually, the empty plot will change towards the best alternative, as previously discussed. The owner of each plot (IFM or traditional farmer) is graphically shown in the simulation through the use of different type of lines, representing each type of producer (small, medium, big and IFM). This allows to seeing the evolution in the number of the different types of actors.

The MAS simulation results have shown that, if the current price structure is maintained, the number of rented plots will tend to increase. As a consequence, the number of plots managed by IFMs has increased. With the current conditions of agricultural profit, it is very difficult for a traditional producer to sell his/her land just for profitability reasons (condition that makes the traditional producer to sell), maintaining a balance between cropping, cattle-breeding and rented plots.

Three results of the DinamicaParcelaria model simulation are presented in the figures below (Cases). The cases are a subset of the combination of three parameters:

- the way the rent value is determined. This value can be: i) determined by the IFM as 1 $ higher than the best alternative –crop or cattle- or ii) defined as 35% of the value earned by producing soybean;
- the evolution of soybean price. This evolution can be: i) sinusoidal or ii) increasing sinusoidal, which starts with very low prices for soybean and ends with very high soybean prices,
- the presence of the IFM, which can be present or not in the simulation.

If the IFM is not present, there won't be rented plots, therefore, they won't be able to determine the rent value. The reason that makes the situation where the IFM determines the rent value is supported by the idea that they can pay traditional producers more (for their rented land) than if the traditional producer produces cattle or soybean by himself in his plots (evidently as long as the IFM continues to earn a positive net profit from his activity).

CASE 1:

Rent Value: determined by the IFM as the best alternative plus one money unit: rent value = MAX(soybean_profit; cattle_profit) + 1$

Soybean Price Evolution: sinusoidal (ranging from historical min. and max. values).

Presence of IFM: yes (and determining the rent value as indicated above).

Note: the X-axis of both graphs has the same scale so they can be analyzed together.

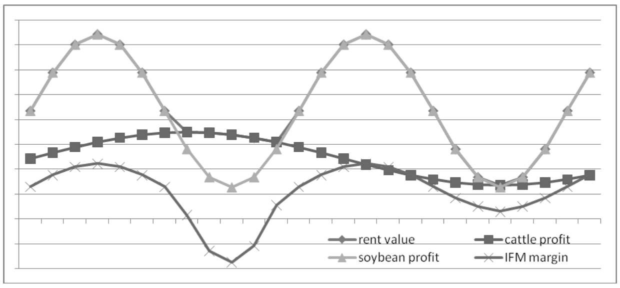

Figure 3: Evolution of Profits (incl. rent) and IFM's Margin Through Time

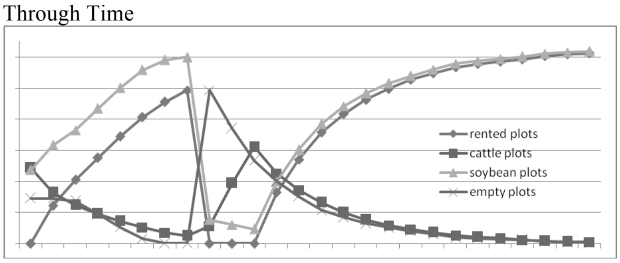

Figure 4: Evolution of Land Use Through Time

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CASE 2:

Rent Value: defined as 35% of the value of soybean.

Soybean Price Evolution: increasing sinusoidal (starting from very low prices up to very high soybean prices).

Presence of IFM: no (it is not present in the simulation, so no plots will be rented).

Note: the X-axis of all four graphs has the same scale so they can be analyzed together.

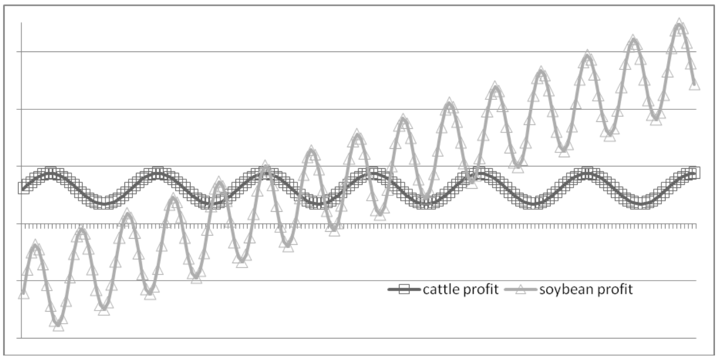


Figure 5: Evolution of Cattle & Soybean Profits Through Time

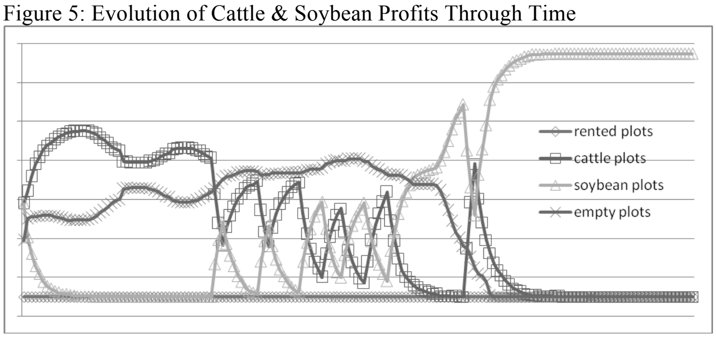


Figure 6: Evolution of Land Use Through Time

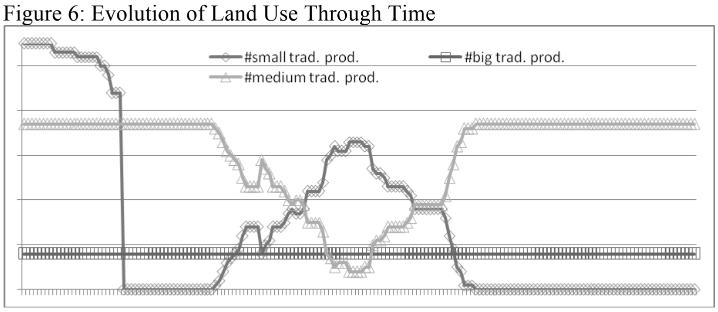


Figure 7: Evolution of Traditional Producers Through Time

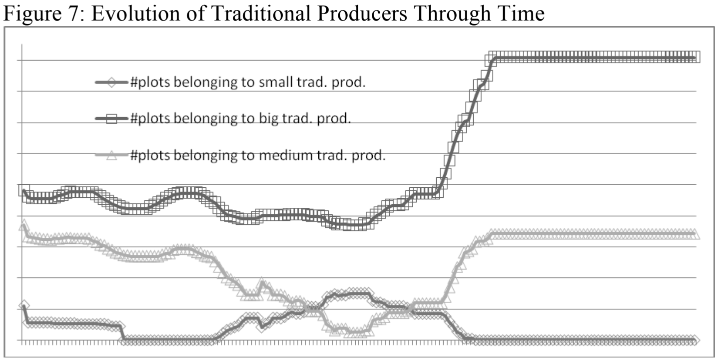


Figure 8: Evolution of Traditional Producers' Size Through Time

Cattle-breeding profit is always considered as evolving with a sinusoidal function with historical minimum and maximum values (normal distribution).

CASE 3:

Rent Value: determined by the IFM as the best alternative plus one money unit: rent value = MAX(soybean_profit; cattle_profit) + 1$

Soybean Price Evolution: increasing sinusoidal (starting from very low prices up to very high soybean prices).

Presence of IFM: yes (and determining the rent value as indicated above).

Note: the X-axis of both graphs has the same scale so they can be analyzed together.

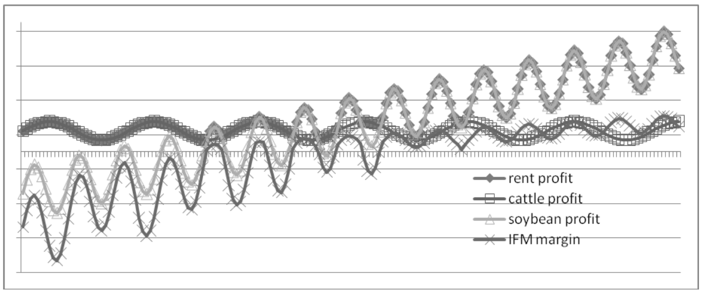


Figure 9: Evolution of Profits (including rent) and IFM's Margin Through Time

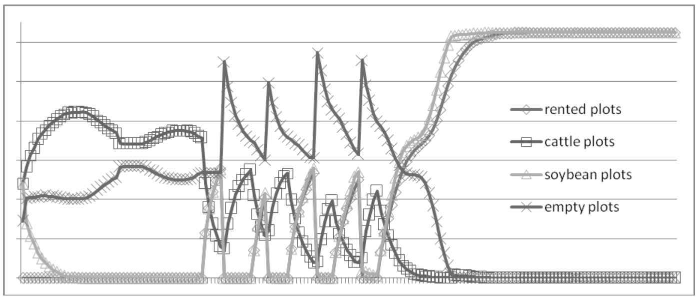


Figure 10: Evolution of Land Use Through Time

It is important to outline that the simulation results obtained so far are still limited, since the model is under construction. We will enhance it by introducing variability in traditional producers' productivity, including lands of lower quality and less productive potential. New factors influencing decision-making processes (such as tradition and environmental values) will be also considered in future simulations.

4.1.3 First Conclusions About DinamicaParcelaria

From the analysis and synthesis of the simulation outcomes, it is possible to conclude that new ways of land use have emerged in the Rio de la Plata Basin region, with a steady increase of large-scale cropping that was not present by the end of the past century. Among other results, the simulations have led us to conclude that:

a) If the decisions of traditional producers are supported by the expected profit and with a normal price distribution (Case 1):
   - When soybean prices are good, the IFM rents all plots for agriculture. There are no changes in land property. There is no concentration of land concerning property, but there will be a concentration of land use. Traditional producers will not sell their plots, and they will tend to rent all of them.
   - If the IFM is willing to pay a fixed rent value in tones of product (Case 2):
   - It could be the case that for traditional producers is more profitable to produce soybean by themselves (if rent is less profitable) so no rent will occur.

- In this case, the simulation outcomes showes that big traditional producers would buy land in order to grow more soybean crops, so land property as well as land use concentration would occur. Small traditional producers would tend to extinction (see Figures 7 and 8).

b) If the price of soybean increases (Case 3):

- Even if IFMs do not exist there still is a continuous crop usage. Also, land property concentration will occur where originally small and medium producers would disappear.
- In any case, cattle is moved out to non-farming areas of lower quality lands.

The preliminary simulations using MAS confirms the hypothesis that this tool has a good potential for exploring the evolution of these kinds of systems.

It should be taken into account, however, that the results obtained are limited since the referred model is still under construction.

However, the DinamicaParcelaria model clearly suggests that both international market price variations and agriculture regulations have a significant influence on the transformation of high quality land from livestock production into cropping fields.

It would be of major importance to re-evaluate land use dynamics and its causes, since the social sustainability of family farmers is at stake. The importance of the sustainability of those livelihoods has been already pointed out in the Introduction: family farmers represent a large part of total producers and support the existence of multiple rural populations in the Rio de la Plata Basin region. The DinamicaParcelaria model allows us to anticipate and act in prevention, facing potential land use changes associated to economical, ecological and social changes. However, socio-psychological variables should be included in future versions of the DinamicaParcelaria model in order to improve the study of farmer's trajectories at the micro level. This cannot be achieved without an interdisciplinary approach, as we well discuss in the Conclusion.

4.2 ARAPEY

Through his Arapey[5] MAS Model, Morales Grosskopf (2007) studies the strategies of livestock producers in a region in which technological changes have not – surprisingly enough - been translated into significant land use changes.

Though the Arapey Model is not focusing exclusively on family livestock producers - it does not distinguish among companies devoted to cattle-breeding, big estancias (South American ranches) or family farmers -, the model simulation results can be widely applied to traditional family farmers. It aim is to explain how the different farm's trajectories can be reproduced modeling the different livestock farmers strategies, independently of their size.

The model proves that livestock producers' trajectory variations depend on factors that go well-beyond technical transformations. Some of those factors, such as biological efficiency (which depends on the employed technology) are internal to the farmer's production unit. Other factors are external to the production unit, such as natural hazards, especially droughts and extreme cold, and market oscillations.

According to our experience, even those internal and external variation sources cannot completely explain land use changes (or, in this case, absence of change) that occur in some specific regions. Multi-Agent Systems were used to explore the "Strategic decisions" made by livestock producers and the different trajectories[6] of farmers in certain time and space scales. The results were later compared with the perceptions of key-informants, including livestock-producers and extension agents working on the field of our study.

The purpose of the Arapey simulations was to prove the possibility of modelling different strategies[7] and to simulate their consequences on time and space scales (Morales et al 2005 a y b;

[5] Arapey is the name of the region which the model represents.

[6] In systems thinking, "trajectory" refers to the series of successive states through which the system proceeds over time. Trajectories might represent the long-term behaviour of the system. This is our case.

[7] A "strategy" is, in a broad sense, a long-term plan of action designed to achieve a particular goal, most often "winning". Strategy is differentiated from tactics, or immediate actions with resources at hand by its nature of being extensively premeditated, and often practically rehearsed. Strategies are used to make the problem easier to understand and solve. When speaking about livestock production in the Pampa biome, "winning" should not, however, be restricted to profit maximization. To

Morales Grosskopf 2007). In order to achieve this goal, we have chosen to focus on the differences among three types of livestock-producers. The chosen variables for establishing the typology are their chosen financial strategy and their animal charge[8] strategy. The three types share the production activity (cattle-breeding) and its results, that is in the same year and with the same stocking rate they obtain the same results. They also share the context-environment in which they deploy those activities. The above-mentioned strategies were widely known by the author, which has a long-standing experience in working directly with the farmers (Morales et al 2005 a y b). However, Morales discovered that the short, medium and long-term impacts of those strategies on the farmers' trajectories were far from being understood, at least by using the usual methodologies, using short term economic considerations.

Figure 1: The Strategies of Cattle-Breeders – Typologies

	Financial Strategy	**Animal Charge Strategy**
Conservative	Safe	Safe
Intermediate	Safe	Risky
Enthusiastic	Risky	Risky

The results show that the farmers' trajectories (as evidenced by the evolution of their production units) are influenced by their financial and stocking rate strategies. The production unit trajectories show little sensitivity to parameter changes in the chosen variables (i.e. interest rate changes and price changes). These results confirm our initial hypothesis: production efficiency (resulting from operative decisions) are not sufficient to successfully describe farmers' trajectories. A second conclusion is that trajectories need – in order to be understood – a description of the farmer's strategic decisions. In other words, decisions which are not directly linked to the annual cycle of operations should be also taken into account.

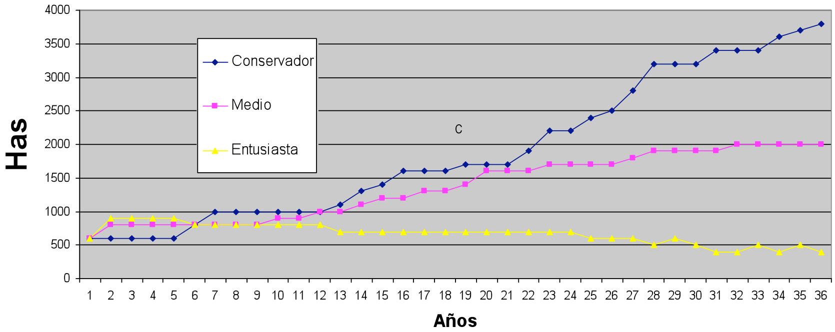
After running the Arapey model, two new strategic decisions as a causal of variation in farm trajectories (different from the technical operations and the environment) have been identified (Figure 2). These two strategic decisions have an impact on the production units' trajectories in the sense of modifying them. At least two unexpected results took place during the simulation:

1. The patrimonial increase of the conservative cattle-breeder is higher than in the other two cases (intermediate and enthusiastic).
2. When the financial strategy remains the same, the animal charge strategy alone alters the production units' trajectories. Even if there differences exist, there are no "breaks".

the contrary, as we stated at the beginning of our article, family farmers can consider "wining" to be able to maintain their livelihoods through livestock production and to continue living in their properties, in direct contact with nature.

8 Animal Charge: number of animals per hectare (i.e. 1/1 = 1 animal in 1 hectare).

Figure 2: Production Unit's Surface Evolution



4.2.1 Expressing the Different "Points of View".

In order to be verified, the results and functioning of model simulations must be coherent with the knowledge generated from different sources (Wilson 1999). Coherence can be checked through the use of model probes. According to their type, probes can facilitate the correction of the model functioning or even describe their results in the usual parameters of the involved actors. The use of probes facilitated the crosschecking of the simulation results with the farmer's knowledge and first-hand experience. The results "validation" took place both in personal interviews and workshops with the participation of many livestock farmers.

4.2.1.1 Verification and Participation

The difficulties of crosschecking the results of MAS simulations with available data have been pointed out by authors such as Manson (2000), and Gilbert and Terna (1999). For this reason, we have chosen to use the Arapey model for simulation in a relatively recent period of time, 1970- 2004. Those specific 34 years were chosen because of the author's previous experience with the region during that period. The existing experience would enable the modellers to detect absurd results. At the same time, the chosen period of time was long enough to facilitate the detection of different results of applying the simulated strategies.

According to Moss and Edmonds (2005), multi-agent systems facilitate a direct correspondence between what is observed and what is modelled. Because of this, crosschecking of the simulation results can be anecdotic or "common sense".

With the purpose of checking their own perceptions with the Arapey outcomes, the model was run in the presence of livestock producers, union representatives, agricultural managers and rural technicians. Before displaying the model results, the author questioned the participants about the results that, in their opinion, could be anticipated.

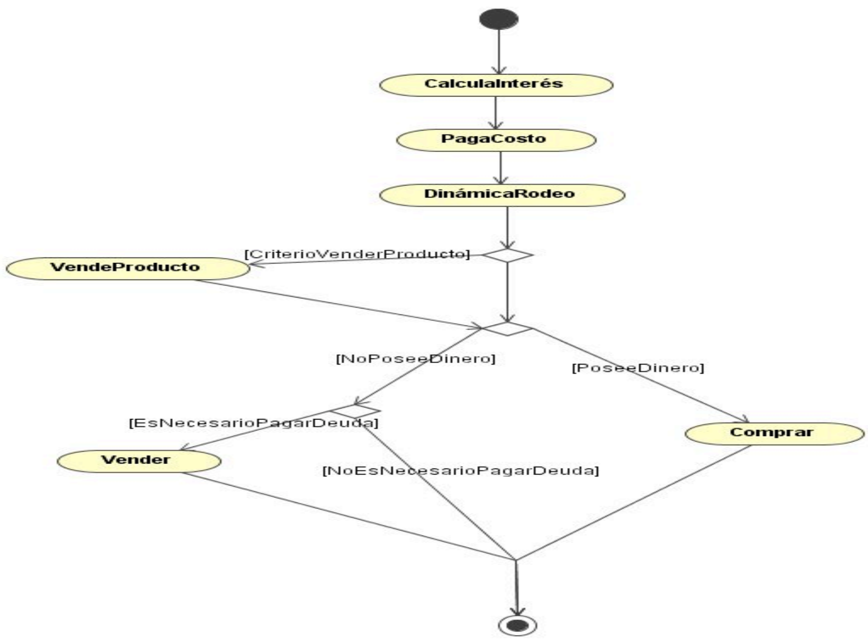
It was interesting to discover that the participants did not anticipate any outcome, even when consulted about situations that were clearly familiar to them. However, once presented with the simulation results, they widely agreed with them. Therefore, the simulation facilitated the construction of new knowledge which was coherent with what they already new. It is difficult to state, however, whether this could be defined as a learning experience. Ison et al. (2000) have defined learning as the enlargement of the array of options and action opportunities as perceived by the observer. If we use this definition, we can then conclude that the Arapey experience with rural actors facilitated learning.

Since the Arapey model is based on intuitive descriptions in terms of objects and agents (Figure 3), people with a certain experience with livestock production find it usually easy to understand the Arapey functioning. Sharing Arapey simulations with farmers and rural technicians demonstrated that participants spontaneously link the model results with their own personal experiences. Crosschecking the model results with their previous knowledge was then easy to be done. This is essential for successful MAS models, since the only way for a user to trust the model and its results is to be able to explore its assumptions (Sorensen and Kristensen 1992).

Besides intuition, a complex situation can become more understandable if it is communicated without ambiguities through the use of diagrams, as proposed by Hubert B. (1994), and Larkin and Simon (1987). As with the DinamicaParcelaria model, the activity diagram of the Unified Modelling Language (OMG 2003) has resulted useful for obtaining clear explanations, with low degrees of ambiguity. In our model, the modellers' assumptions can be explored without the need of being a computing expert or a biologist theorist. This becomes particularly important when models are used as a tool for decision-making (Lynam and Stafford Smith, 2003).

Checkland (1999) proposes a rule that simplifies the interpretation of model simulations: the activities represented in the diagrams must oscillate between 5 and 9 (Morales et al. 2005 a). This can be visualized in the activity diagram presented in Figure 4.

Figure 4: UML Activity Diagram - Arapey Model



The above Activity Diagram shows that in each simulated year, each production unit updates its cash existence by paying its costs, estimating its interest rates (positive or negative) and selling their production in coherence with the farmer's strategy. Following, and after considering its financial balance and criteria, the farmer will buy or sell cattle or land.

When confronted with the Arapey simulations, the participants confirmed that the displayed results were similar to what had actually happened in the studied period of time (1970-2004), even when admitting that they model results showed this in a strongly simplified way. This allows the author to state, along with McCown (2002) that policy implementation challenges can be addressed through the use of decision-making support tools such the Arapey model.

4.2.3 Conclusions About the Arapey Model

4.2.3.1 Difficulties When Dealing with “Slow” Variables

Morales (2007) evaluated options to “enhance” the Arapey model by allowing agents to learn and, as a consequence, to be able to modify their strategies. However, the dynamics of strategy change is not clear. In everyday, reallife situations, farmers seldom change their strategies, unless they face important shocks or events, internal or external to the production unit or household.

But the big question remains: how do cattle-breeders evaluate the consequences of their actions in order to learn from observation and to adjust their adaptation strategies to a changing environment? After examining the model simulations, the author discovered that the differences among strategies show up slowly in the model. In practice, this implies the presence of a “memory-information system” (Le Moigne, 1994) that is usually inexistent. The exception is people with long-term experience (Berkes y Folkes 2002).

4.2.3.2 Future Areas to Be Explored through Arapey.

The Arapey Model opens questions about the role of the financial system and the – at least alleged – need to permanently adjust productive and management estrategies in order to cope with a dramatically changing environment.

In the context of those questions, the information system used by the cattle-breeders (agents) of the Arapey model becomes particularly relevant. Arapey puts into question the efficiency of the information systems offered to those systems and provides tips to its construction.

It is widely accepted that before creating an information system we must model the system that we pretend to inform (Checkland y Holwell 1999). In this case, the used information consists of some date internal to the production unit, such as the cash existences and the animal charge.

CONCLUSION

Which are the limits and potentialities of MAS for studying the social impact of territorial transformations in South America? After analyzing the outcomes of MAS simulations for understanding cattle breeders’ trajectories (Arapey) traditional farmers’ patterns of land use (DinamicaParcelaria) we can confirm our initial hypothesis: MAS contribute to improve the understanding of the impact of the strategies adopted by family farmers, who must decide between sticking to traditional livestock production and investing in the higher and shorter-term profitability of soybean production.

Crosschecking of MAS simulations with farmers’ experiences in participative methods confirm that the consequences of livestock producers’ strategies on the territory can be effectively explored through the use of MAS models. MAS models simulate the action of different agents at the micro level and take into account different “points of view”.

When dealing with “slow variables”, which are of difficult identification, MAS models contribute to register their variations and consequences and, accordingly, to accelerate the learning processes.

Simultaneous modelling and simulation of physic -biological and decisional systems facilitate the perception of the global qualities of a system through a bottom-up understanding of micro production units. This creates coherence between what is experienced by farmers at the micro level and what is estimated at the macro level (Epstein & Axtell 1996; Beinhochker 2007; Epstein 2007).

This micro-macro coherence of data contributes to inform both private and collective action, enabling stakeholders to address the challenges of global change (SCOPE 68 2007). The agriculturization of the Pampas and the consequent rural exodus of family farmers is, in that sense, one of the challenges presented by global change to social sustainability.

MAS models offer an interesting perspective of the coupled socio-ecological systems and their possible evolution. They prove that actor heterogeneity produces complex landscape use patterns at the local level. The studied multi-agent models (Arapey and DinamicaParcelaria) also prove that family farmers' strategies cannot be explained as the single consequences of economically rational decision-making processes (a decision maker who has perfect information and makes decisions that yield the greatest economic benefit). Together, the combination of complexity and heterogeneity in decision-making processes suggests that single-policy prescriptions designed to target landowners are unlikely to effect broad-scale changes in land-management practices without reference to specific landowners and their circumstances.

To effect the greatest change, a diversity of policies (or policies targeting households with different socioeconomic contexts) is more likely to achieve desired socio-environmental outcomes. Although agent-based models help address the challenge of micro-macro integration, for example, they require data at multiple organizational scales, ranging from individuals through households, communities, and nations. Two particular areas that require attention are the roles of social networks and institutions in individual decision making. Agent based models without difficulty handle spatiotemporally explicit data, but these data and a profound knowledge of the ongoing processes must first exist (Manson and Evans 2007). Interdisciplinarity (especially with the inclusion of social sciences) and multi-stakeholder knowledge integration is necessary to cope with this kind of problems.

Considering new internal and external factors which affect the decision making processes, as well as the underlying values of family farming as a livelihood, are essential when coping with social (un)sustainability *vis a vis* globalization-led territorial transformations. Recent qualitative and quantitative studies conducted in the Pampa biome of Brazil, Argentina and Uruguay (Litre et al, 2007; Waquil et al. 2006) have discovered that livestock family farmers have an extremely positive vision of their activity, that they define with expressions such as "the good life", "a healthy and natural life", and "real freedom". Even if many livestock family farmers admit that life is becoming more and more difficult due to the difficulty to cope with the increasing challenges of globalisation, a wide majority among them still consider their way of living much more peaceful and rewarding than the desperate look for profit maximization that they attribute to large cities. Pampean family farmers establish strong links within their identity and their environment, as they believe that the cultural survival of their families and communities depend on the economic and environmental sustainability of their farms.

These underlying visions of the activity and values, and their translation (or not) into environmentally sustainable practices should be better explored, as recent studies on "subjective indicators" of sustainability have proved (OCDE, 2007). In this sense, multi-agent models such as DinamicaParcelaria and Arapey have a great potential for accelerating learning and adaptation process (Lynam and Stafford Smith, 2003, Morales et al. 2006). To transform their potentialities into reality, the analysis should be enhanced through the inclusion of social and also political and institutional variables in order to improve our understanding of the complex dynamics of agro-eco-systems. This becomes especially important because the desired – and possible – changes do never rely exclusively on the declared logics (Checkland and Holwell 1998, Lynam and Stafford Smith, 2003).

For that, an interdisciplinary analysis, including social and institutional approaches, becomes unavoidable (Tiessen, 2007, Manson et al, 2007).

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