Multi-agent systems applied to land use and social changes in Río De La Plata Basin (South America)

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Abstract: *Dynamics in agrarian systems of Uruguay and Argentina present some positive aspects as well as other potentially devastating. Traditional producers have a production strategy based on looking for a balance between cattle and agriculture production, alternating pasture and crops. A new actor: investment-fund-managers rent the land for agriculture production, and from our team's discussions emerged that they follow a strategy similar to that of financial capital: decide what to do in terms of the expected net profit. Economical, ecological and social consequences could be expected. Modeling and simulating with Multi-Agent-Systems was used for exploring the system's evolution with the objective of improving our understanding of the agrarian system and to contribute to the envision of possible effects on land use caused by changes in product prices and/or policy changes. The model considers the soil resource as having productive potential and assumes that each traditional producer annually decides whether to change or not its production activity over 25% of its land units or to rent to investment fund managers. A six year database with historical production activity revenues and product's prices was used for the simulation, where each simulated year randomly chooses from this database. The first results of these simulations generate questions about the dynamics of the natural resources, challenge the survival of traditional farmers and anticipate landscape changes associated to economic, ecological and social changes. A strong variability was observed from year to year in respect to land use. Results show that if the current price structure is maintained as well as the relation between net profits of agriculture and cattle, then a tendency to expand Investment Fund Managers' lands will occur. We conclude that the newly arrived Investment Fund Managers tend to induce a rent activity in traditional producers as well as a substantial increase in agricultural activities (decreasing cattle activities). The historical cattle-agricultural model well known in Uruguay and Argentina has been challenged by market-imposed conditions.The simulation shows that social effects should also be foreseen.*

Keywords*: land use change, simulation models (modelling), farm(farmers) strategy(ies).*

Introduction

Recently observed changes in agrarian systems of the Rio de la Plata Basin (MERCOSUR, South America), with important similarities between the different regions, should be given some thought in the sense of possible economical, ecological and social consequences, which could be anticipated from these changes in the farming sector due to the explosive introduction of soybean crops and a new push of the forest industry. The increase in the soybean production is common to all countries in Rio de la Plata Basin since it is mainly produced by large companies and 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 practices. The evolution in the structure of farms has lead to a new kind of actor (agricultural investment fund managers -IFM from now on- that rent land) which together with all these changes raise questions about which could be the positive and negative aspects, what kind of actors will still be present in the near future and if it possible to state if agriculture is going through a concentration process similar to those observed in other sectors of the economy? This soybean expansion process takes over new lands now devoted to agriculture or leaving behind traditional activities. For example, in Uruguay between 2000 and 2006 the total agricultural area increased in 17% due to the expansion of soybean crops which have multiplied by 25 (in area) in just 5 years. 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.

This expansion in the production takes place in an agrarian structure characterized by an increasingly economic concentration, which affects thousands of producers, especially small ones since in just 5 years 45% of them were no longer agricultural producers. (Arbeletche et al., 2006) This expansion process is also characterized by the denationalization of the agricultural production, the coming of a soybean complex related to a monopolistic offer of inputs (especially seeds and machinery), an almost monopolistic export demand, and a set of technologies driven by a few foreign companies.

As in Argentina, Brazil and Paraguay, this expansion is not the result of a planned productive one, based on social and economic development objectives. Instead it is the result of capital advance (mainly financial capital) due to: new conditions result of the disappearance of legal regulations that existed until the 90's; technological changes related with direct sowing and transgenic crops; and finally the increasing demand of agricultural products by the international market.

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, and therefore, related to economic or socio-political disturbances (Paruelo et al., 2006).

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

The current agricultural situation with these unprecedented changes requires us to imagine and examine actions that could leverage the positive aspects and mitigate the negative ones. In this context, this work refers to a Uruguayan region and can be seen as a case study with relatively abundant information, where a methodology can be adjusted and later be used in similar circumstances, or in comparison to other regions of the Rio de la Plata Basin. Displace

Objectives

The objectives of this work are:

- Identify and model the strategies followed by the different kinds of farm producers present in Uruguay, in order to analyze and understand their long term consequences.
- Develop a model to allow the simulation of the evolution of the different kinds of producers and land uses.
- Perform these exploratory and prospective simulations using a Multi-Agent System constructed by our multidisciplinary team over the Cormas simulation platform (Cormas 2006).

This first approach focuses on analyzing possible evolutions in land use (on lands perfectly suitable for crops) as well as the evolution in the different kinds of producers. This approach is supported by various ongoing works from different team members, such as the construction of a typology of producers' behavior and their corresponding organization of production activities, among others.

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Methods and Materials

The general characterization of the agrarian dynamics was created from secondary information, national and international statistics and from other documents that allow a comparison with other regions as well as with other historical information.

The typology used was developed from 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 methodology that was followed consists of three stages:

Stage I: A multidisciplinary team was formed with researchers, teachers and extensionists from Uruguay and Argentina that complement their competences in understanding a phenomenon that is present in various areas of the Rio de la Plata Basin, with their similarities and differences.

Stage II: In order to make the model (understood as the construction of an image that highlights those aspects of interest for the modeler, ruling out others) we used UML (Unified Modeling Language, Fowler 2003). The use of a common modeling language (such as UML) enables many people to communicate with each other with little ambiguities (Krutchen 2003) and allows us to understand, analyze, communicate and improve a given situation or reality. UML defines a model as a set of diagrams, accepting from the beginning that no single diagram can represent an entire system. UML proposes 13 different kinds of diagrams: six of these are for describing the structure of a system (being the Class Diagram the most widely used) and seven are for describing the dynamic of a system (being the Activity Diagram and the Sequence Diagram the most widely used) (Fowler 2003).

Stage III: 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.

This simulation, using Multi-Agent Systems (MAS from now on) is supported by object oriented programming and it is getting more and more attention as a tool, especially adapted for these kind of analysis. MAS appears as a tool especially adapted when trying to simulate the functioning and evolution of systems composed by heterogeneous agents interacting among themselves that are influenced by their location in space, in situations that can or cannot be of equilibrium (Bonabeau, 2002; Weiss, 1999; Bousquet, 2006; Janssen 2002). When trying to study systems that include human behavior, prospective simulation take distance from the normative approach that has been common in many sciences, and this difference is important enough as to classify it as a “new kind of science” (Bradbury 2006).

Axelrod (1997) proposes that agent-based simulation constitutes a third way of acquiring knowledge, different from the usual deduction and induction methods. The potential of MAS to study the dynamics of natural resources that interact with society has been identified more than a decade ago (Bousquet, 2006; Janssen 2002). Their capacity to simulate social systems (Gilbert & Terna 1999) and its interaction with heterogeneous elements such as those that dynamically characterize ecological systems, place them as an adequate tool for such situations (Parker et al., 2002; Moran & Orstrom 2005).

The actual way of modeling depends on the right judgment of the team that is involved (Ericsson & Penker 2000), and the task of defining the level of abstraction is quite sensitive since the main capacity of the modeler consists of choosing what to include and what to exclude from the model, keeping in mind the objectives (Schmuller 2004, Holland 1998).

According to Le Page & Bommel (2006), a MAS is a set of agents with the ability to act and communicate; with perception, communication, production, consumption and data transformation within an environment; a topological space; a whole that contains agents and objects; a resource for communication and action; passive objects such as resources, organization plans, or ways coordinate represented by the set of rules and relations.

Each agent presents a collective behavior, consequence of its perceptions, representations and interactions with the environment and with other agents, and it communicates with these, it has a perception of them as well as of the environment, and it perceives and acts over objects (Janssen 2002; Weiss 1999). In equation-based models, agents are frequently (and sometimes even implicitly) assumed as representing an average behavior, so these approaches cannot take into account the interactions between agents or their heterogeneity.

Results

The Different Kinds of Producers

Beginning from the typology created by Arbeletche and Carballo (2006) two subsets of producers were identified: first, traditional producers that integrate into their production system crop and pasture rotations, as well as cattle production; and second, newly arrived farmers (IFMs) that base their productive systems in continuous crops over rented land. Within the first subset of traditional producers, a second classification was done identifying three kinds of traditional producers according to their amount and combination of farm resources (land, work and capital): family producers (also called "small producers"), medium size entrepreneurs (also called "medium producers") and full size entrepreneurs (also called "big producers").

Description of the Simulation Model

The model shows the interactions generated through the use of the land (agriculture and cattle) and the ownership of the land (rented or owned). The model looks forward to generate knowledge about these aspects and understand the relation among traditional producers and IFMs. The strategy of the latter consists of renting land (plots) in order to intensively and continuously produce soy bean crops. The model also considers that traditional producers (including small, medium and big) who have a history of combining cattle and crops, are profit-sensitive, meaning that they will try to practice whatever activity is more profitable.

The model simulates the behavior of both, traditional producers and IFMs and assumes that the three kinds of traditional producers behave in the same way (that means that their rules are the same) but they differentiate in the amount of resources they manage (that means the number of plots they own and/or operate). Therefore traditional producers risk their properties, while IFMs manage capital (other people's money).

In our model, IFMs rent (and eventually release) plots as long as traditional producers are willing to put some of their plots to rent (and eventually recover them). This means that the initiative of whether to rent or not is taken by the traditional producers according to their decision rules, represented by a UML Activity Diagram (which will be later presented).

The main assumptions of the model are the following:

- Traditional producers can give up for rent one or more of their plots,
- They can only give their plots for rent to the IFM,
- The rented plots are always used for continuous crops (the only activity of IFMs) at the very moment they are rented, and it can or cannot coincide with its previous use,
- Traditional producers can buy and sell plots between themselves, as well as give up for rent to the IFMs, which can only rent plots to traditional producers (therefore IFMs cannot buy land).

Model's Structure

Figure 1 presents the UML Class Diagram (Fowler 2003) with the (simplified) structure of the model. Class Diagrams graphically show the main components of the model (classes) and their associations (relations between classes). Each component (class) contains its name (first section), its attributes (second section) and its operations (third section) and during the simulation run, each individual element will be an instance of some class (for example, producers A, B and C will all be instances of the class Traditional). The relations among classes are typically an association (represented by an open-ended arrow) or a specification (represented by a close-ended arrow).

The right-hand side of the diagram represents the resources (the **Plot** class) and their use (classes **LandUse**, **Cattle**, **SoyBean** and **Empty**). Each plot (land unit) has just one use at a time. Each plot (100 hectares) can be either rented (to the IFM) or sold (to other traditional producers). When they are not exploited their state is empty. Exploitation then consists of choosing between cattle and soybean. Each productive activity has its own cost and price that evolve according to the market (this evolution will be discussed later).

The left-hand side of the diagram represents the agents present in the model: the classes **InvestmentFundManager** and **Traditional**, both subclasses of **Producer**. Any producer can manage a set of **N** plots (represented by the relation **Producer –manages→ Plot**) but only traditional producers can own a set of **N** plots (represented by the relation **Traditional –owns→ Plot**). According to the number of plots owned by a traditional producer we further classify them in "small", "medium" and "big" producers (represented by the attribute **type** of the **Traditional** class). Only traditional producers can buy and sell land (represented by the operations **buyPlot()** and **sellPlot()**) since this is a strategy that IFMs do not have (they systematically choose to sow continuous crops –soybean– over rented plots using high technology which gives them a productivity 30% higher than traditional producers).

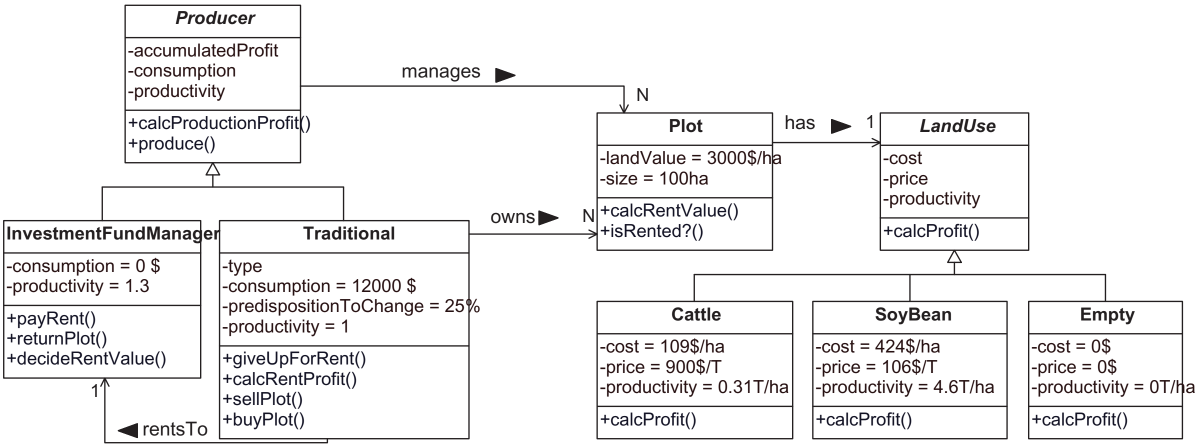

Figure 1. Class Diagram

Traditional producers can use their plots in the following ways (represented by the relation **Plot –has→ LandUse**):

- continuous crops (every year with double crop, covering 100% of the surface with a winter crop and 80% with a second summer crop),
- cattle fattening,
- rent the plot to the IFM, or
- leave it empty.

The decision of what activity to perform depends on which activity is the most profitable (gross margin) for the traditional producer. The current version of the model assumes that all three kinds of traditional producers are in the same conditions to perform any of these activities.

Model's Rules

Figure 2 presents the UML Activity Diagram (Fowler 2003) with the (simplified) strategy of traditional producers (remember that only these kinds of producers are proactive, while IFMs react to the actions of these). The Activity Diagram graphically shows the activities that a traditional producer can perform during a certain year. The diagram has a beginning (represented as a solid circle) and an end (represented as a circle & dot) and in between there are tasks or individual activities (represented as rounded rectangles). These tasks or activities are connected with arrows that represent the flow within the diagram and this flow can be controlled by decisions (represented as rhombus). Each decision has a set of outgoing flows, each one with a guard (represented as a boolean yes/no expression within) and only one of these guards can be true at a time (therefore choosing that outgoing flow).

The diagram could be divided in three sections: left, center and right. The left-hand side corresponds to the situation in which the traditional producer presents good levels of accumulated profit that year (remember that the diagram shows the decision rules for one year and is "executed" each year of the simulation period). These "good levels" are defined as having enough accumulated profit for (at least) the next two years (that means that he/she can produce and consume for at least two more years). Under this situation the traditional producer could try to regain its rented plots (if this activity is not more profitable than cattle or soybean). Eventually the traditional producer could even buy one (or more) plots. The right-hand side of the diagram corresponds to the opposite situation: the accumulated profit is not enough for the next year, so the traditional producer is faced to, firstly, try to give up plots for rent, and secondly, try to sell one by one their plots, until either of two things happen: they can upfront the next year, or declare bankruptcy (and leave the simulation). The center part of the diagram corresponds to the intermediate situation: the traditional producer has enough money to face only the next year. In all cases (except of course when declaring bankruptcy) the traditional producer plans the activities for next year (considering renting an activity) and according to market prices (which can evolve and will be discussed later) they will produce (or rent) up to 25% of their plots. This percentage (which can actually change, but for clarity reasons was fixed in 25% in the diagram) is represented as the **predispositionToChange** attribute of the **Traditional** class. This attribute is necessary since if not present, traditional producers could change 100% of their managed plots from one year to the other.

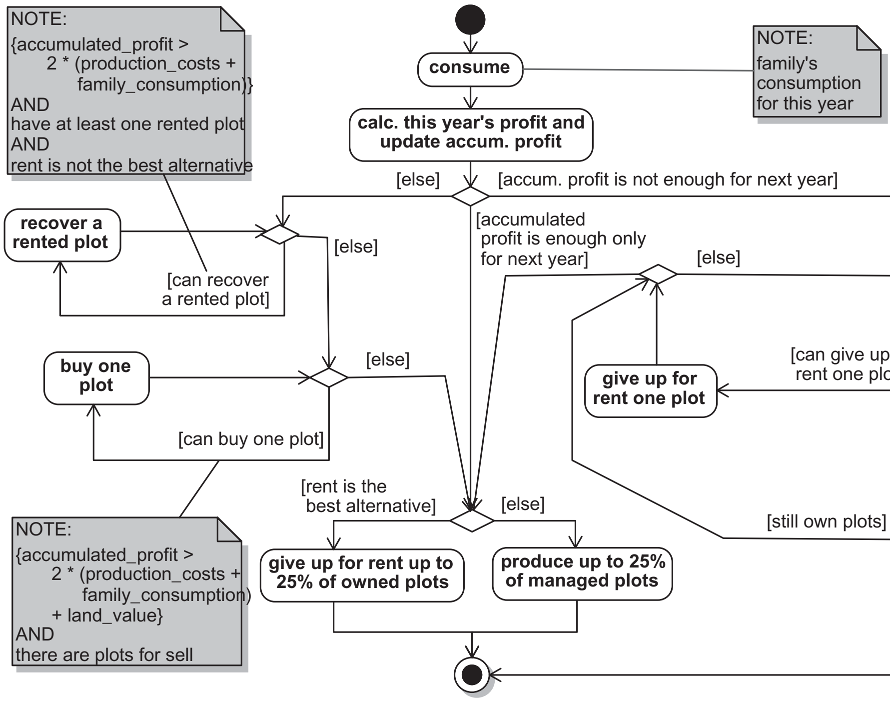

Figure 2. Activity Diagram for Traditional Producers

IFMs' activities and rules are much simpler, since each year they produce soybean crops over all the plots they have rent. Even though these kind of producers are not proactive (meaning that traditional producers are the ones that offer their plots for rent) they can decline a rent offering if the price of the rent is too high (meaning that they would have no profit with such high rents). They can also return rented plots in that situation. The simulation model also allows IFMs to determine the price of rent (this is a parameter that can be turned on or off and it will be discussed later when showing the simulation results for different input parameters).

Simulation Initialization

The simulation assigns to each kind of traditional producer (small, medium & big) a certain amount of land units (plots) with a randomly selected land use that can be cattle fatening or continuous crop. Each plot (according to its use) has a certain production level that corresponds to average values of Uruguay. Each plot can be bought, sell or rented at market values. All values of products have been average market values for the last five years, and are the same for all producers. Rent and property values are the same as market values.

All plot yields are the same for all traditional producers.

At the beginning of the simulation (time step zero) each traditional producer is given a randomly selected activity, and while the simulation runs, they change this activity according to their decision rules (that is, according to that activity that is most profitable) due to the evolution of prices. Giving up for rent one or more plots is also considered an activity. The initial distribution of the number of each kind of traditional producers was taken from the results of the typology performed over traditional farmers corresponding to the year 2005. The capital of each traditional producer is initiated in zero and increases with each randomly assigned plot. When the simulation runs, each time the traditional producer buys, sells, rents or recovers a rented plot, this capital is updated. This capital is also updated when calculating the profits for each year due to the activity of each managed plot.

The current version of the model assumes that all traditional producers have the same annual cost of living (consumption) which is subtracted from the profits for that year.

Simulation

The last two tasks of the Activity Diagram relate to planning the next year: the current version of the model look for the most profitable activity (rent, cattle or continuous soybean crop) concerning the gross margin (production * price - cost). 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 no note that if a certain activity is systematically the best alternative, then traditional producers will tend to move towards this activity, year by 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 (since they are being managed by the IFM).

Regarding land use, the simulation graphically shows with different colors what use is given to each plot at each time step (year). These uses can be: continuous soybean crop, cattle, 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 this empty plot will change towards the best alternative, as discussed. Who owns each plot is also graphically shown during the simulation with different colors representing each type of producer (small, medium, big and IFM). In this way we can see the evolution in the number of each type of producer.

The results show that if the current price structure, as well as the relationship between agriculture or cattle profit over owned land vs. rent profit over that land, are maintained, there will be a tendency to increase the number of rented plots, which in our model means an increase in the number of plots managed by IFMs. 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 crop, cattle and rented plots.

Three results (or cases) of the model are shown as follows, which are a subset of the combination of three parameters: the way the **rent value** is determined (this value can be: a) determined by the IFM as 1 $ higher than the best alternative –crop or cattle- or b) defined as 35% of the value earned by producing soybean); the evolution of **soybean price** (this evolution can be: a) sinusoidal or b) increasing sinusoidal, which starts with very low prices for soybean and ends with very high soybean prices) and the **presence of the IFM** which can be present or not in the simulation. If it 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 on 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 have the same scale so they can be analyzed together.

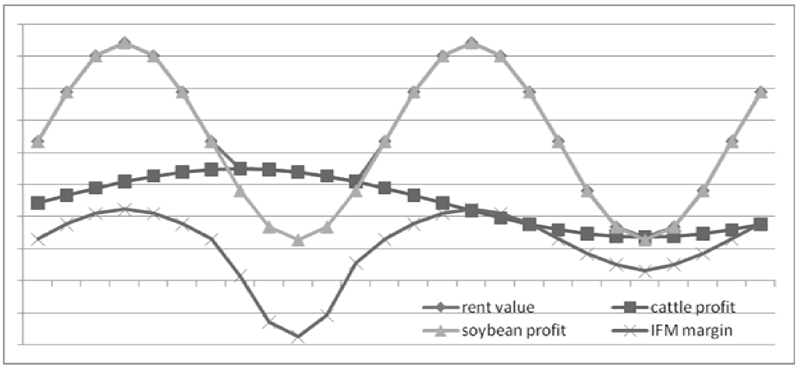

Figure 3. Evolution of Profits (incl. rent) and IFM's Margin Through Time

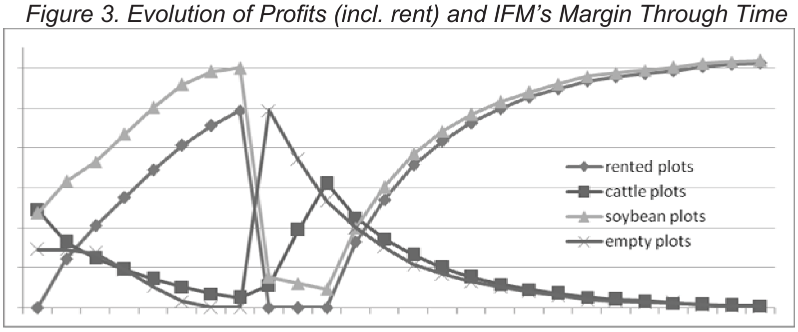

Figure 4. Evolution of Land Use Through Time

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 have the same scale so they can be analyzed together.

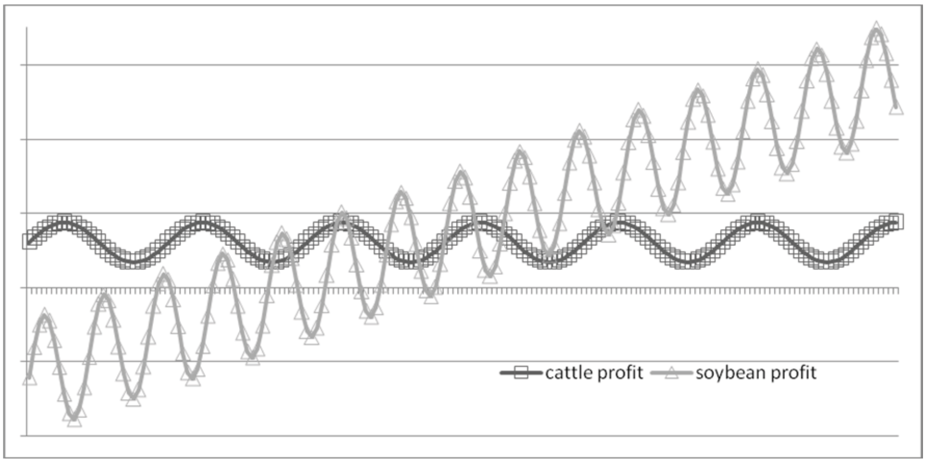

Figure 5. Evolution of Cattle & Soybean Profits Through Time

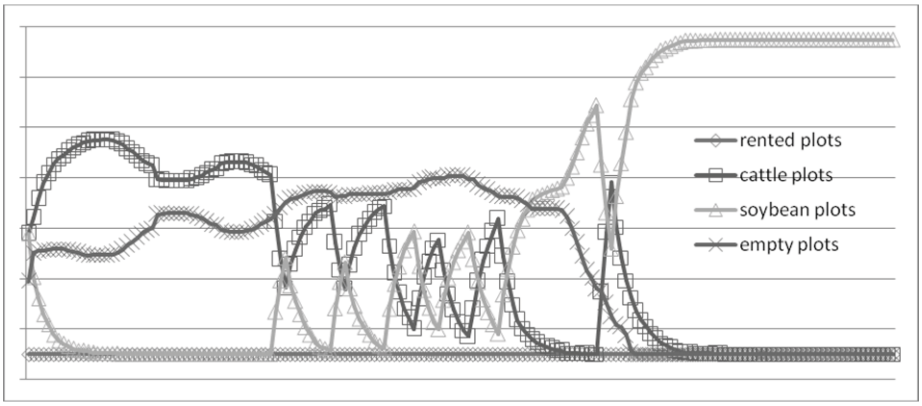

Figure 6. Evolution of Land Use Through Time

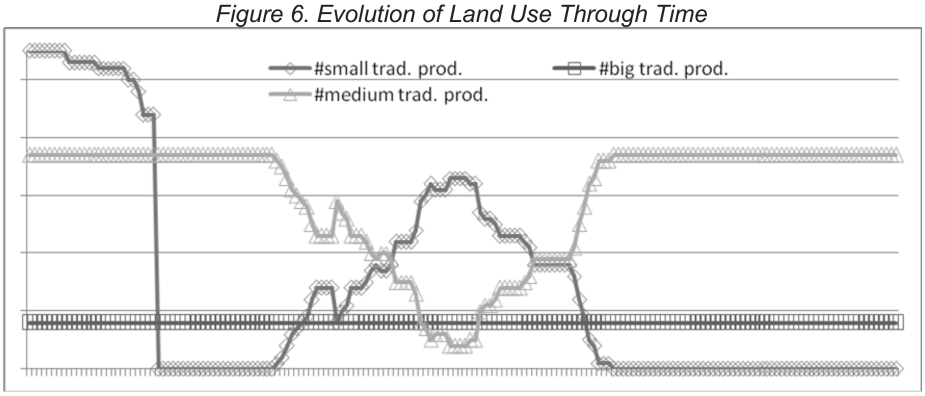

Figure 7. Evolution of Traditional Producers Through Time

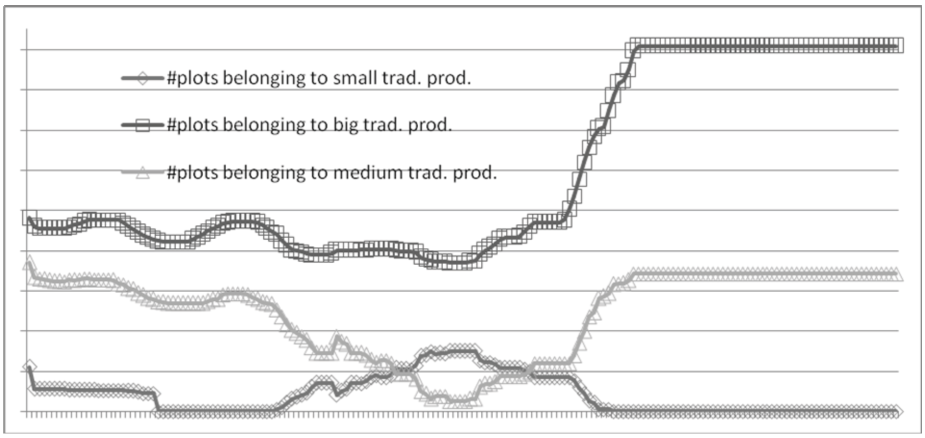

Figure 8. Evolution of Traditional Producers' Size Through Time

Cattle 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 have the same scale so they can be analyzed together.

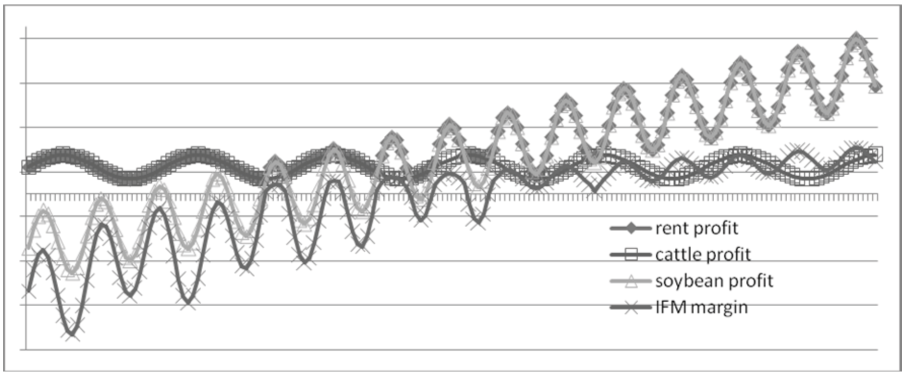

Figure 9. Evolution of Profits (including rent) and IFM's Margin Through Time

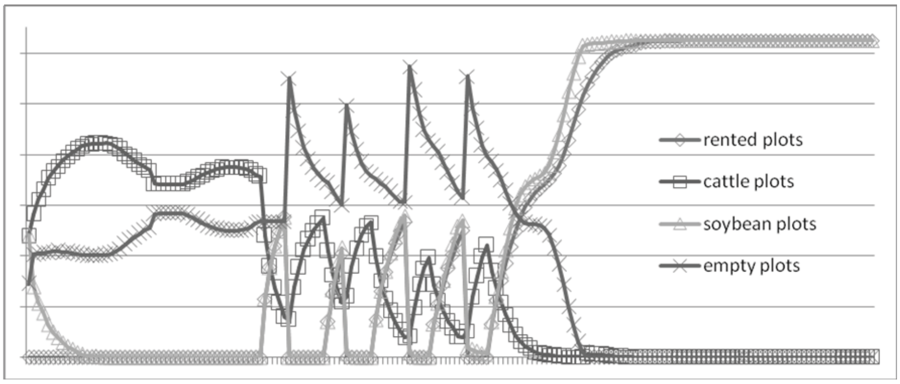

Figure 10. Evolution of Land Use Through Time

The results achieved so far are limited since the model is still under construction. We will extend it introducing variability in traditional producers' productivity, including lands of lower quality and less productive potential.

Conclusions

From the analysis and synthesis of all available data we can conclude that new ways of land use appeared in the Rio de la Plata Basin region, with a steady increase of continuous crops that was not present at the end of the past century. From the modeling and simulation we conclude that:

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 do 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 showed 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).

If the price of soybean increases (Case 3):

- Even in the case that IFMs do not exist there still is a continuous crop usage. Also, a land property concentration will occur where at first 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 that we have done showed us that this tool has a good potential for exploring the evolution of these kinds of systems.

It should be considered that the results obtained are limited since we deal with a model under construction. However, the model suggests that changes on international prices and policies in countries like Uruguay and Argentina greatly determine that the best quality lands are mainly used for agriculture.

It would be of major importance to reevaluate land use dynamics and its causes, since the survival of small producers is in stake (which represents a large part of total producers and support the existence of multiple rural populations in the Rio de la Plata Basin region). On the other hand, these models allows us to anticipate and act in prevention, facing potential land use changes associated to economical, ecological and social changes.

References

Arbeletche, P., Carballo, C., 2006 Crecimiento agrícola y exclusión: el caso de la agricultura de secano en Uruguay in Proceedings VII Congreso de Alasru, Quito, Ecuador, november 6-10.

Arbeletche, P, Carballo, C., 2006 Sojización y concentración de la agricultura uruguaya in Proceedings del XXXIV Congreso de la Asociación Argentina de Economía Agrícola Córdoba, Argentina, october 18-20.

Bonabeau E., 2002 Agent-Based modeling: Methods and techniques for simulating human systems in Proceedings of the National Academy of Sciences of the USA 99: 7280-87.

Bousquet F., 2006 Multi-agent systems, companion modeling and land use change in Lambin E.F. & Geist H. (eds): Land-Use and Land-Cover Change. Local Processes and Global Impacts. Springer. Berlin Germany.

Bradbury R., 2006 Towards a new ontology of complexity science in Perez P. Batten D. (eds) Complex Science for a Complex World. ANU E Press. Camberra Australia.

Cormas, 2006 Ressources naturelles et simulations multi-agents. CIRAD. URL: http://cormas.cirad.fr

Ericsson H. E., Penker M., 2000 Business Modeling with UML. Business Patterns at Work. OMG Press. John Wiley & Sons, Inc. USA.

Fowler M., 2003. UML Distilled, Third Edition. A Brief Guide to the Standard Object Modeling Language. Addison Wesley. USA.

Gilbert N., Terna P., 1999, How to build and use agent-based models in social science, URL: http://web.econ.unito.it/terna/deposito/gil_ter.pdf/

Holland J.H. 1998. Emergence. From Chaos to Order. Basic Books.

Janssen M. (Ed.), 2002 Complexity and Ecosystem Management: The Theory and Practice of Multi-agent Approaches, Edward Elgar Publishers.

Kruchten P. (2003) The Rational Unified Process: An Introduction, Third edition. Addison Wesley. 302 pp.

Lambin E. F., Geist H., Rindfuss R. R., 2006, Introduction: local processes with global impacts, in Lambin E.F. & Geist H. (eds) Land-Use and Land-Cover Change. Local Processes and Global Impacts. Springer. Berlin Germany.

Lambin E. F.; Geist H. J.; Lepers E., 2003, Dynamics of land-use and land-cover change in Tropical Regions, Annu. Rev. Environ. Resour. 20:205-41.

Le Page C., Bommel P. 2006, A methodology to building agent-based simulations of common pool resources management: from a conceptual model designed with UML to its implementation in Cormas.

CORMAS, in Bousquet F.; Trébuil G.; Hardy B. (eds) Companion Modeling and Multi-Agent Systems for Integrated Resource Management in Asia. Los Baños (Philippines): International Rice Research Institute. 327-350.

MGAP-DIEA, 2001, Censo General Agropecuario 2000, Montevideo, Uruguay.

Moran E. F., Orstrom E (eds), 2005), Seeing the forest and the trees: Human-environment interactions in forest ecosystems, MIT Press, Cambridge London.

Parker D.C. Berger Th. Manson M., 2001, Agent-Based Models of Land-Use and Land-Cover Change, Report and Review of an International Workshop October 4–7, 2001 Irvine, California, USA Edited by: Parker D.C., Berger T., Manson S.M. URL: http://www.indiana.edu/%7Eact/focus1/ABM_Report6.pdf

Paruelo J.M, Guerschman, J.P.; Piñeiro, G.; Jobbágy, E.G, Verón, S.R.; Baldi, G. y Baeza, S., 2006, Cambios en el uso de la tierra en Argentina y Uruguay: Marcos Conceptuales para su análisis, Agrociencia. Vol. X N° 2 pp. 47 – 61.

Schmuller J. 2004, Sams Teach Yourself UML in 24 hours, SAMS Publishing USA.

Weiss G. (ed), 1999, Multiagent Systems. A Modern Approach to Distributed Artificial Intelligence, MIT. USA.

Web pages consulted: URL: http://www.mgap.gub.uy/diea and URL http://www.mgap.gub.uy/opypa