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Agent-based Modeling of a Rental Market for Agricultural Land in the Argentine Pampas

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Abstract: More than half of land in the Argentine Pampas is cropped by tenants. The importance of production on rented land motivated development of a LAnd Rental MArket (LARMA) model with endogenous formation of Land Rental Price (LRP). LARMA is a "hybrid" model that relies partly on easy-to-implement concepts from neoclassical economics, but addresses drawbacks of this approach by being integrated into an agent-based model that involves heterogeneous agents interacting in a dynamic environment. LRP formation assumes economic equilibrium: it is the price at which supply of rental land area equals land demand. LRP depends on (a) the "willing to accept" price (WTAP) of owners renting out land due to lack of capital or dissatisfaction with recent economic progress (a Minimum Progress Rate, MPR, is targeted), and (b) the "willing to pay" price (WTPP) and working capital (WC) of potential tenants. Land owners base WTAP on estimated profits they could achieve from operating their farms. Potential tenants base WTPP on their target gross margin for the upcoming cycle. Initial experiments with simplified economic contexts (input and output prices) did not show significant differences in regional land tenure from LARMA vs. use of an exogenous, fixed LRP. Nevertheless, simulated LRP trajectories reproduced observed dynamics: prices followed consistently the trajectories of conditions driving crop yields and profits. Consideration of MPR induced many land owners to rent out their farms, thus increasing the proportion of rented land. LARMA is a first attempt to translate equilibrium-based models into a model involving agent heterogeneity and social embeddedness. Many LARMA components will be used in a subsequent model with full bilateral transactions.

Keywords*:* agricultural land markets; agricultural production; land tenure; Argentina.

1. INTRODUCTION

The region of central-eastern Argentina known as the Pampas is one of the main cereal and oilseed producing areas in the world [*Calviño and Monzón*, 2009]. In this region, climatic, technological, institutional, and economic drivers have induced significant changes in land use and structural characteristics of agricultural production systems [*Paruelo et al.*, 2005]. Three related patterns have been observed in recent decades: (a) "agriculturization," or a rapid increase of cropped area, (b) an increase in the average size of farms, accompanied by the disappearance of smaller farms, (c) an increase in the amount of land operated by tenant farmers. In this work, we focus on land tenure changes.

Land tenure in the Pampas has changed rapidly in the last few decades. Currently, about half of the land is cropped by tenants [*Piñeiro and Villarreal*, 2005]. The global and national economic contexts enhanced recent profitability of agricultural production. However, because land sale prices remained high – due to a highly-uncertain economy and inexistent credit – Pampas farmers resorted to leasing land to expand production. Every year, farmers in the Pampas actively compete for rental land to maintain or increase their cropped area. As land became more commoditized, competition led to a doubling of land rental prices since 2001.

Because of the importance of production on rented land in the Pampas, we developed a LAnd Rental MArket (LARMA) model that involves endogenous formation of Land Rental Price (LRP). LARMA is integrated into a comprehensive agent-based model (ABM) designed to explore and understand structural changes and land use in the Pampas [*Bert et al.*, 2010]. We adopt agent-based modeling as a suitable tool to quantitatively model agricultural systems, their structural change, and endogenous adjustment to policy interventions. This approach helps capture the effects of individual heterogeneity among farms and farmers, and of interactions among agricultural decision-makers and relevant institutions [*Berger et al.*, 2006].

The paper is organized as follows: first, we provide background on modeling land rental markets. Then, we briefly describe the dynamics of the ABM in which the LARMA component is embedded. Third, we detail LARMA design and implementation. Finally, results from simplified simulation experiments using LARMA are presented.

2. APPROACHES TO MODELING LAND RENTAL MARKETS

Different approaches may be used to model land sales or rental markets [*Kellermann et al.*, 2008; *Polhill et al.*, 2005]. Common approaches are based on the neoclassical economics approach, which involves major assumptions such as full rationality and perfect information [*von Neumann and Morgenstern*, 1947]. The concept of equilibrium is central to neoclassical economics: under equilibrium, the supplied quantity of a good equals the quantity demanded. The price of a good in the equilibrium state is called Market Clearing Price (MCP) and does not change unless supply and/or demand change.

Despite its widespread use, the neoclassical approach is receiving increased criticism. Major objections include the assumption of fully rational behavior, the fact that real markets often are out of equilibrium, the assumption of a "representative" agent that ignores heterogeneity, and the lack of explicit representation of the social embeddedness of markets [*Granovetter*, 1985]. Current software tools supporting agent-based modeling (ABM) capabilities render feasible the representation and exploration of complex economic systems [*Tesfatsion*, 2007]. Filatova et al. [2009] and Parker and Filatova [2008] point out that ABMs may help relax restrictive assumptions: for instance, heterogeneity of agents and interactions among them seem highly relevant to the dynamics of land markets.

We introduce LARMA, a land rental market model with endogenous formation of Land Rental Price (LRP). LARMA is a "hybrid" market model that relies partly on neoclassical economics for ease of design and implementation, but also addresses drawbacks of this approach by integrating the market model into an ABM framework. For instance, LARMA relaxes the assumption of a representative agent by considering agents with heterogeneous characteristics that may induce differences in the prices that agents are willing to pay or accept for land rental. Although LARMA still does not include bilateral trading between agents, it does involve other interactions (e.g., farmers monitor economic outcomes achieved by their peers) leading to adjustments in agents' willingness to pay/accept certain land rental prices. The formation of (a) farmland supply and demand and (b) prices that agents are willing to pay or accept for land are endogenously and dynamically determined depending on agents' working capital (WC) and personal characteristics.

Of course, land markets as heterogeneous and spatially organized markets are far from the ideal assumption of perfect competition where homogenous goods are traded with equal access, free entry and perfect and complete information [*Kellermann et al.*, 2008]. Nevertheless, characteristics of the land market in the Pampas allow us to rely on the neoclassical approach without resigning much realism. First, the LRP in a given region and for a given soil quality is well known by most agents. Thus, agents can assess possible economic outcomes stemming from their decision to rent land. Second, LRPs for farms in the same region and with the same soil quality are very similar, regardless of farm size (i.e., rental land can be considered a commodity). Third, a large number of agents participate in the rental market; due to high demand, farmers are willing to rent land relatively distant from their home base. Finally, Pampas farmers are marked-oriented (subsistence agriculture is virtually inexistent) and aim to achieve as much profitability as possible.

3. AN AGENT-BASED MODEL OF AGRICULTURE IN THE PAMPAS

Concerns about the environmental and societal impacts – sustainability of production, life support systems and farmers' livelihood – of structural changes and land use in the Pampas motivated our development of an agent-based model (ABM) to gain insight on recent changes and explore plausible evolution [*Bert et al.*, 2010]. Our model focuses on the northern part of Buenos Aires province near Pergamino, the most productive sub-region of the Pampas. The main activities are soybean, maize, and the wheat-soybean double crop.

The model environment is a stylized 2-D grid involving a variable number of farms defined at initialization. Each grid cell represents a farm of a certain size, also defined at initialization. All modeled farms have the same soil and experience the same climate – described by daily historical weather at Pergamino. Although the environment does not represent real geography, the model is spatially explicit because there is a topological relation among cells. We assume that modelled farmers can operate any farm within the target area (i.e., distance to home base is not an issue). The model involves one main type of agent: farmers who either operate owned and/or leased farms, or rent out their land. Each agent may have different land allocation strategies, and personality (risk aversion) and financial (working capital) characteristics. A special "Manager" agent performs calculations that need to be available to all agents.

On each cropping cycle, each agent goes through a series of model steps. At the beginning of a cycle, a farmer updates the area that she will crop in that cycle, deciding whether she can maintain or expand cropped area or, instead, must release some or all of the previously farmed area. The only way to expand production is by leasing additional land; i.e., the model does not include land sales. The "cropped area update" stage includes the LARMA model that forms LRP endogenously. In the next step, farmers adjust their economic aspirations for the current cycle based on the expected status of context factors (climate conditions, output prices, input costs). This initial adjustment is part of a dynamic update of aspiration level, AL [*Diecidue and van de Ven*, 2008] in the model. Subsequently, farmers allocate land among a set of viable Activity/Managements (AMs), defined by the combination of (a) an Activity (maize, soybean and wheat-soybean) and (b) agronomic Management decisions such as genotype, planting date and fertilization. After land is allocated, the yield of each AM is retrieved from lookup tables built using historical weather as input to crop models in the Decision Support System for Agrotechnology Transfer (DSSAT) package [*Jones et al.*, 2003]. Economic returns are calculated from simulated yields and crop prices and input costs (model inputs): the result is an updated WC for each farmer at the end of the production cycle. "Attainment discrepancy" [*T K Lant*, 1992] between economic returns achieved by both a farmer and relevant peers and the farmer's previous aspirations drive a second AL adjustment. The model then moves to the next cycle.

4. CROPPED AREA UPDATE AND LAND RENTAL MARKET MODELS

This section describes the "cropped area update" (CAU) sub-model in our ABM and the LARMA component for LRP formation. The CAU sub-model involves three main stages: (a) definition of potential farmland supply and demand, including the formation of Land Rental Price (LRP) via LARMA, (b) definition of actual farmland supply and demand (once LRP is defined), and (c) matching of supply and demand.

4.1 Definition of potential farmland supply and demand and formation of LRP

Following the neoclassical economics approach, we assume that LRP results from the equilibrium between demand (agents interested in renting in additional land) and supply (agents who must rent out their land). All farms (of a given soil quality) will be rented at the formed LRP during a cropping cycle. Formation of LRP by the LARMA component involves three consecutive steps: (a) the identification of potential supply and demand; (b) the formation of "Willing to Accept Price" (WTAP) and "Willing to Pay Price" (WTPP); and (c) the calculation of a Market Clearance Price (MCP) representing the LRP for the current cropping cycle. Each step is described below.

The first step in the CAU sub-model is the definition of potential supply and demand and the identification of agents who need to form WTAP and WTPP. Agents who could potentially rent additional land must form a WTPP; conversely, owners who cannot operate their farms need to form a WTAP (Table 1). At the start of a production cycle (prior to formation of LRP) the model assesses whether each farmer can: (a) return to active farming (for landlords), (b) maintain previously cropped area or, (c) expand production by renting in additional land, or instead (d) must release some or all previously farmed land. This assessment is based on a farmer's ability to cover (a) implantation costs (labors, seed, and agrochemicals) for the most expensive AM, and (b) rental costs (for rented farms).

The assessment of a farmer's ability to operate a given area is scheduled first for landlords because, if they return to farming, their land no longer will be available to previous tenants. After dealing with landlords, the model assesses the ability of remaining active farmers to operate a certain area. If farmers are not able of operate a certain area, they must retire (rent out their farms or release rented farms). But even when farmers are able to operate a given area, they may not necessarily get involved in farming. For instance, even when landlords have sufficient WC, the decision of return to active farming is stochastic[1]. Also, even when the owners only have sufficient WC to continue operating their farms, they test if they are satisfied with their economic evolution over the recent past. An economic progress rate – PR, defined as the relative increase in a farmer's WC over the most recent 5 cropping cycles – is calculated and compared to a minimum progress rate (MPR) defined arbitrarily for each farmer at initialization. If the farmer's PR $\geq$ MPR, she is satisfied and will continue farming. Conversely, if the farmer's PR < MPR, she will *consider* renting out her farm (despite having the WC to operate it) and therefore needs to form WTAP. As discussed below (Section 4.2), this farmer will actually rent out her farm only if the formed LRP is higher than her WTAP.

A second step involves the formation of WTAP and WTPP. The WTAP is the minimum price that an owner is willing to accept to rent out his farm. *We assume that an owner's WTAP is based on an estimation of the profits that he could achieve from efficiently operating his farm.* Note, however, that profits from crop production are inherently variable and risky. Risky production incomes and the sure income from land rental must be compared on an equal, risk-free basis. To do this, we compute the Expected Utility (EU) of a range of production incomes and then express that EU as a Certainty Equivalent (CE). The CE is the "for sure" value that would make a farmer indifferent between facing risky cropping outcomes or accept the minimal-risk rental fees [*Hardaker et al.*, 2004, p. 30]. EU is computed for AMs which have yielded the top 10% gross economic profits (i.e., assuming the farm is well-managed) in each of the three most recent cycles. We assume that an owner's WTAP is equal to the computed CE. We stress that WTAP depends on the farmers' personality (risk aversion) and financial (initial wealth) characteristics.

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[1] Two mechanisms are considered for landlords to return to active status: (a) a constant probability of return (25%) and (b) a probability of return that decreases with time as landlord and becomes 0 after six cycles. Both mechanisms reflect the real-world low proportion of returning landlords, as they get used to steady incomes with minimal risk. The second mechanism intends to reflect that, the longer a farmer stays as landlord, the more technically outdated he becomes.

Table 1. Summary of agents who need to form WTAP and WTPP on a given cropping cycle. Agents may have different land tenure status on each cycle: (a) "owners-only" crop owned land only, (b) "owner-tenants" crop both owned and rented land, (c) "tenants-only" operate only rented land, and (d) "landlords" rent out their land.

Who needs to form WTAP?	**Who needs to form WTPP?**
• Landlords who do not have sufficient WC to return to active farming. • Landlords who, despite having sufficient WC, *choose* not to return to active farming.	• Landlords who have sufficient WC and decide to return to active farming.
• Owners-only who do not have sufficient WC to continue operating their farms. • Owners-only who, despite having sufficient WC, rent out their farms because they are dissatisfied with their recent economic progress.	• Owners-only who have sufficient WC to continue operating their farms and are satisfied with their recent economic progress.
• Owner-tenants who do not have sufficient WC to continue operating their own farms (they must release all rented farms *and* rent out own land).	• Owner-tenants who have sufficient WC to continue operating their farms.
	• All tenants-only

The WTPP is the maximum price that a potential tenant is willing to pay to rent a farm. We assume that a prospective tenant's WTPP is based on the economic gross margin (GM) he would like to achieve during the upcoming cycle. We also assume that the target GM is quantified by the farmer's AL adjusted by expected status of context factors (cf. Section 2). Note that the context-adjusted AL weaves together a farmer's own experience and his expectations of future states of the world [*T Lant and Shapira*, 2008]. We assume also that a farmer seeks a minimum return rate for the capital that he must lay out at the beginning of a cycle. This capital – which we refer to as "Committed Capital" – includes crop implantation costs and land rental. The WTPP is then calculated as a function of both the target GM and the desired minimum return rate (space limitations preclude details of the calculation).

The third step is formation of the Market Clearing Price (MCP). In LARMA, the MCP represents the LRP at which the quantity demanded and quantity supplied of land area for rental is equal. To compute MCP, first a list is built with all WTAP and WTPP values: this list represents possible market price (MP) values. For each MP, the model assesses (a) the total number of hectares that could be rented in by potential tenants (i.e., demand curve). The area that each potential tenant could rent is the ratio of his WC and WTPP; this area is summed for each MP over all tenants for which WTPP $\geq$ MP. (b) The total number of hectares that could be rented out by owners (i.e., supply curve). The total area that would be rented out at a given MP is calculated by identifying land owners for whom MP $\geq$ WTAP and then adding up farm areas for those owners. The MCP, then, is solved as the intersection of the demand and supply curves. This value becomes the price at which all land will be rented during a cropping cycle, or LRP.

4.2 Definition of actual farmland supply and demand

The second stage in the CAU sub-model involves the definition of actual supply and demand of farmland for the current cropping cycle. Some of the farms/farmers involved were identified in a previous stage (Section 4.1). In other cases, however, an actual LRP is necessary before a farm or farmer can be added to the actual supply/demand. Owners who have sufficient WC to remain active but are unsatisfied with their economic progress choose to rent out their land only if LRP $\geq$ WTAP. All tenants need an actual LRP to assess whether they can maintain their previous rented area or expand. Tenants with insufficient WC must release some rented area (these farms are added to the supply).

4.3 Matching actual farmland supply and demand

The third stage of the CAU sub-model matches actual supply and demand. This process involves iterating over the list of potential tenants. A farmer is initially selected from the list of potential tenants[2]. This farmer evaluates the list of rental farms available and selects suitable choices. First, she excludes farms that she cannot afford. Then, she excludes farms that are too small[3] to be of interest: this intends to capture the empirical fact that a farmer operating a large area will not consider renting a small farm. Once the first selected farmer rents a farm (or passes), she stays in the list of potential tenants if she has remaining WC; otherwise she is deleted from the list. Next, another farmer is selected and the farm selection process is repeated. The process ends when all potential tenants have rented a farm or passed. If farms remain available after all potential tenants have been cycled through, previously inactive agents (created at initialization) are assigned to a farm and given sufficient WC to operate that farm.

5. RESULTS

This section presents results from simplified simulation experiments aimed to verify the operation of LARMA. Farm numbers and size distribution were based on Argentina's 1960 Agricultural Census: 4624 farms with areas from 50 to 5000 hectares were simulated. The initial proportion of rented farms (10%) also was consistent with the 1960 Census. Input costs and output prices were constant and represented 2002-2007average values. Crop yields were the only input varied, but a simplified trajectory was specified: a see-saw pattern of (a) low, (b) medium, (c) high and (d) medium yields was cyclically repeated.

The first simulation involved a baseline scenario (Scenario 1) in which an exogenous, constant LRP (240 $\$$ ha^{-1}) was specified[4]. Two other simulations (Scenarios 2 and 3) relied on endogenous LRP formation by LARMA. Scenario 3, however, included an MPR of 25% over five years.[5] Each experiment involved 100 simulated cropping cycles.

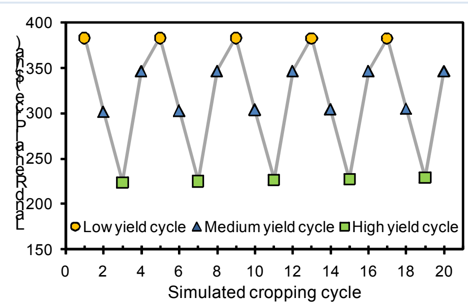

Figure 1. Simulated Land Rental Prices for 20 cropping cycles (Scenario 2). Orange circles indicate years with high crop yields and profits. Conversely, green squares denote years with low yields and profits. Blue triangles are medium yield years. See text for discussion of the dynamics of LRPs.

Although our simplified experiments do not allow strict comparisons with historical values, simulated LRPs are generally consistent with LRPs observed in the last few years. Modelled LRPs (Scenarios 2 and 3) ranged between 200 and 380 $\$$ ha^{-1}.

A cyclical pattern of simulated LRPs (Fig. 1) results from the input see-saw of crop yields and profits. The highest LRPs occur during low-yield years (indicated by circles in Fig. 1). Although this appears counter-intuitive, remember that LRPs respond to yields and profits in preceding years, and are independent of yields experienced during a given year. For example, year 1 has low yields and profits, thus agents' ALs and thus WTPPs decrease; in parallel, WTAPs also

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[2] Two selection mechanisms have been modeled: (a) all potential tenants have the same probability of being selected and, (b) the probability of being selected is proportional to the potential tenant's WC – reflecting an advantage for wealthier farmers.
[3] The minimum area acceptable for leasing is defined as a function of the total area operated by a farmer.
[4] Average land rental price for 2002-2007 (the period for which model economic conditions are defined).
[5] This value was selected in consultation with regional experts.

decrease because profits expected from operating owned land are lower. The combined result is that LRP for year 2 decreases. Conversely, year 3 has high yields and profits, thus LRP increases in year 4. Interestingly, whereas the crop yield pattern has three levels (high, medium and low), simulated LRPs show four distinct values. This is because the mechanisms of WTAP and WTPP formation – which in turn define LRP – are influenced by yield levels in the three most recent cropping cycles. The two intermediate LRPs both correspond to medium-yield years. These years, however, can be preceded by (a) a decreasing high-medium-low sequence – which results in the lower of the two intermediate LRPs, or (b) an increasing low-medium-high sequence – which results in the higher of the two intermediate LRPs.

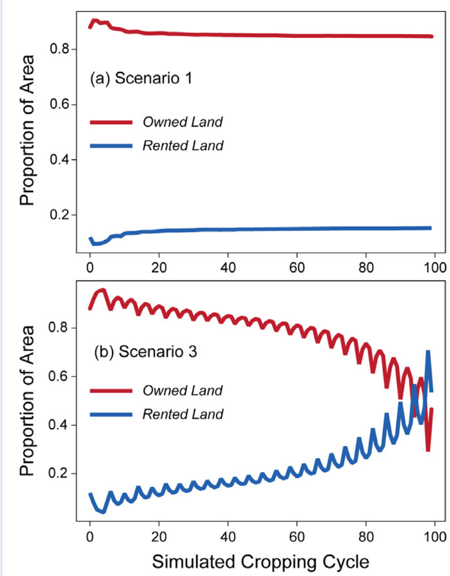

Figure 2. Proportion of total area operated by owners and tenants in Scenarios 1 and 3

The simulated LRP response to preceding yields and profits is consistent with observed dynamics in the Pampas. The two most recent cropping cycles (2008/09 and 2009/10) are a clear example. The 2008/09 cycle was preceded by favorable climate and high output prices. As a result, LRPs were extremely high (340-380 \$ ha^{-1}). However, profits during 2008/09 were low because the worst drought in the last 50 years was experienced. Consequently, LRPs decreased significantly (30 to 50%) in 2009/10.

The inclusion of an endogenous LRP did not have a marked influence on structural and land tenure patterns. In contrast, activation of the MPR mechanism in Scenario 3 induced marked changes in structural and land tenure patterns. The MPR mechanism led to increases in (a) the average area operated by an agent (from 153 has in Scenario 1 to ≈500 has in Scenario 3) and (b) the proportion of area operated by tenants (Figs. 2a vs. 2b). Under the economic conditions assumed for the simulations, there is a large proportion of farmers that, despite being economically viable, do not achieve the desired economic progress (a 25% increase in WC over 5 years). Unsatisfied, these farmers rent out their farms when LRP is higher than their WTAP.

6. FINAL COMMENTS

Land markets and the dynamics on land markets play a crucial role in agricultural structural change. We introduce LARMA, a land rental market model with endogenous formation of LRP for the Argentine Pampas. LARMA is a "hybrid" model that relies partly on easy-to-implement concepts from neoclassical economics but addresses drawbacks of this approach by being integrated into a broader ABM framework.

The simplified simulations performed allowed us to verify the LARMA operation. The introduction of endogenous LRPs did not change noticeably regional land tenure patterns. Regional land tenure patterns were most influenced by mechanisms associated with agents' dissatisfaction with their economic progress, rather than by land rental price itself. Of course, these results are limited by the simplified simulation conditions. We are performing additional simulations assuming realistic simulation conditions (e.g., actual trajectories of crop yields, output prices) in order to assess the ability of LARMA to reproduce the observed dynamics of land rental market in the Pampas. The model presented is a first step towards translating – in the spirit of Parker and Filatova [2009] – classical equilibrium-based models into a framework involving heterogeneous agents interacting in a dynamic environment. We aim to introduce full bilateral trading between agents in the near future.

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