Agent-based Modeling of Land Rental Market: Comparison between Simulated and Observed Prices 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, 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. Simulated LRP trajectories reproduced observed dynamics of prices in the Pampas. Simulated prices were mainly driven by farmers´ profits expectations at the beginning of each cropping cycle and crop yields and profits in recent previous cycles. LARMA is a first attempt to translate equilibrium-based models into a model involving agent heterogeneity and social embeddedness. Many LARMA components may be used in a subsequent model with full bilateral transactions.

Keywords: Agricultural land markets; Agricultural production; Land tenure; Argentina.

1 Introduction

The Pampas of central-eastern Argentina are among the main cereal and oilseed producing areas in the world [1]. Climatic, technological, institutional, and economic drivers have induced significant changes in land use and structural characteristics of agricultural production systems in this region [2]. In this work, we focus on the increase in the amount of land in the Pampas operated by tenant farmers and we model the formation of rental price in agricultural land.

Land tenure in the Pampas has changed rapidly in the last few decades. As in many parts of the world, agricultural land rental is widespread: more than half of the land currently is cropped by tenants [3]. One-year land rental contracts prevail in the region, thus every year farmers must compete actively for rental land. Due to the lack of credit and high land sale prices, leasing land is an attractive alternative to expand production with low transaction costs and limited capital outlays that leave more liquidity available for production [4]. Because of the importance of 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 Pampean agriculture [5]. Agent-based modeling is a suitable tool to capture the effects of individual heterogeneity among farms and farmers, and of interactions among agricultural decision-makers and institutions [6].

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 is embedded. Third, we detail LARMA design and implementation. Finally, we present results from a set of simulations aimed to assess the LARMA capability to reproduce observed changes in land tenure and land rental price dynamics.

2 Approaches to modeling land rental markets

Different approaches may be used to model land sales or rental markets [7, 8]. Common approaches are based on the neoclassical economics approach, which involves major assumptions such as full rationality and perfect information [9]. 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).

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" individual that ignores heterogeneity, and the lack of explicit representation of the social embeddedness of markets [10]. Current software tools supporting agent-based modeling capabilities render feasible the representation and exploration of complex economic systems [11]. Filatova et al. [12] and Parker and Filatova [13] 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 willingness to pay or accept for land rental. Although LARMA 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. The formation of (a) farmland supply and demand and (b) prices that agents are willing to pay or accept for land are 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 [7]. 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. 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 of structural and land use changes in the Pampas motivated our development of an agent-based model (ABM) to gain insight on recent changes and explore plausible evolution [14]. 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 of a certain size defined at initialization. All modelled 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, the farmer adjusts their economic aspirations according to 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 [15] in the model. Then, the farmer updates the area that she will crop in that cycle, deciding whether she can expand, maintain or reduce 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. 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 (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 [16]. Economic returns are calculated from simulated yields and crop prices and input costs (model inputs): the result is an updated working capital (WC) for each farmer. "Attainment discrepancy" [17] between economic returns achieved by both a farmer and relevant peers and the farmer's initial 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 and 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.

A *first step* involves the definition of potential supply and demand to identify those agents who need to form WTAP and WTPP respectively (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, (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).

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 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 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 at initialization. If the farmer's PR ≥ 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

[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.

(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 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 all possible AMs in the three most recent cycles 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 [18, p. 30]. 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.

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 [19]. 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 prices (MP). 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 would 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.

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 included in the actual supply/demand are 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 ≥ 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 move to the actual supply).

4.3 Matching actual farmland supply and demand

The third stage of the CAU sub-model matches actual supply and demand to finally define the area that each agent will crop. 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 farms for rental 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

Here we present results from realistic simulations aimed to assess LARMA's capability to reproduce the recent dynamics of the land rental market in the Pampas. We simulate 20 cropping cycles starting in 1988, when an Argentine Agricultural Census was available to initialize the model (i.e., number of farms, farms size distribution, etc.). Realistic trajectories for the main model inputs (i.e., crop yields, crop prices, input costs, etc.) were based on records from Argentinean trade magazines (e.g., *Márgenes Agropecuarios*).

LARMA reproduced reasonably well the dynamics of land rental prices in the Pampas. Figure 1 shows the simulated Land Rental Price (SLRP) and the range of observed LRPs (OLRPs) for 1995-2007. The Root Mean Square Error (RMSE) was 72 \$ ha^{-1} and the Median Absolute Error (MAE) was 41 \$ ha^{-1}. LARMA captured the timing of large changes or turning points in LRP. For instance, the model reproduced the 1995-96 LRP "jump" associated with an increase in commodity prices (and thus agricultural profits) during that cropping cycle. Similarly, LARMA reproduced the LRP decrease from 1996 to 2000, associated with a progressive drop in commodity prices, followed by an upward LRP trend after 2001, tied to the increase in profitability of agriculture after the devaluation of Argentinean currency that followed the Argentine economic crisis of 2001/02.

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[2] 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.

Despite the reasonable performance of LARMA in reproducing the overall dynamics of LRP, differences remain between simulated and observed prices during specific cycles. To understand these differences, we performed simulations aimed at assessing the sensitivity of LARMA and LRP to uncertainty in input variables. The formation of WTPP – one of the main LARMA processes – is driven by the aspiration level that each farmer updates at the beginning of a cropping cycle. In turn, this update is driven by a farmer's expectations of climate, prices and costs (defined here for simplicity as "favorable", "normal" or "unfavorable"). To demonstrate the need for realistic trajectories of the expected and actual status of climate, prices and costs, we performed a simulation in which, for each cycle, we randomly assigned a status to each of the context factors. In this experiment, LARMA produced very unrealistic results: the RMSE was 127 \$ ha^{-1} and the MAE 91 \$ ha^{-1}. Despite the importance of agriculture to Argentine economy, we found it difficult to obtain reliable data on some contextual factors. In other cases, characterization of the status of some drivers is complex (e.g, what is "unfavorable climate"?). We believe that most of the differences between simulated and observed prices are tied to the uncertainty in defining trajectories of contextual factors.

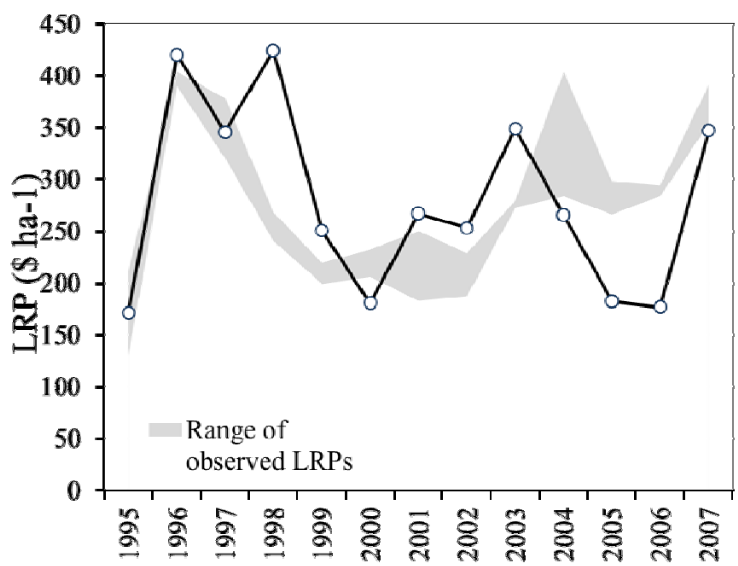

Fig. 1. Simulated (black line with circles) and range of observed (grey area) Land Rental Prices. Observed LRPs are reported in tons of soybean per hectare, but the price of soybean varies in time. The LRP range was calculated using the minimum and maximum soybean prices reported between April and July, when most land transactions take place.

Development of LARMA was motivated by the marked increase observed in the proportion of land cropped by tenants in the Pampas. In addition to simulating the land rental market, one of the main purposes of our ABM is to understand and reproduce evolving land tenure patterns. The land transactions simulated through

LARMA reproduced well the recent increase in land operated by tenants: the model simulated an increase of almost 50% of area farmed by tenants during the period simulated. Although no recent census data on land tenure are available, the simulated patterns are highly consistent with expert estimates of the proportion of rented land in the Pampas.

6 Final comments

Land rental market plays 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 simulations presented in this work allowed us to validate LARMA. The LARMA model was able to reproduce acceptably well the observed dynamics of land rental market in the Pampas. However, we found that simulated LRP was very sensitive to changes in the trajectories of the ABMs´ input variables. In particular, the expected and experienced status of climate conditions, crop prices and input costs. In this sense, the drawbacks in getting realistic information to define input variables may lead to differences between observed and simulated LRPs. The integrated ABM-LARMA framework reproduced the main changes of land tenure observed in the Pampas.

Acknowledgments

This research was supported by U.S. National Science Foundation (NSF) Coupled Natural and Human Systems grant 0709681. Additional support was provided by the Inter-American Institute for Global Change Research (IAI) grant CRN-2031; the IAI is supported by NSF grant GEO-0452325. F. Bert is assistant researcher at CONICET (Consejo Nacional de Investigaciones Científicas y Técnicas) of Argentina.

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