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Simulating agricultural land rental markets by combining agent-based models with traditional economics concepts: The case of the Argentine Pampas

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ABSTRACT

Land exchange through rental transactions is a central process in agricultural systems. The land tenure regimes emerge from land transactions and structural and land use changes are tied to the dynamics of the land market. We introduce LARMA, a LAnd Rental MArket model embedded within the Pampas Model (PM), an agent-based model of Argentinean agricultural systems. LARMA produces endogenous formation of land rental prices. LARMA relies on traditional economic concepts for LRP formation but addresses some drawbacks of this approach by being integrated into an agent-based model that considers heterogeneous agents interacting with one another. PM-LARMA successfully reproduced the agricultural land tenure regimes and land rental prices observed in the Pampas. Including adaptive, heterogeneous and interacting agents was critical to this success. We conclude that agent-based and traditional economic models can be successfully combined to capture complex emergent land tenure and market price patterns while simplifying the overall model design.

1. Introduction

Land exchange among agents related to farming is a central process in agricultural systems. Agents may exchange land through land rental or sales transactions, as part of land markets. Land tenure regimes in agricultural areas emerge from land transactions among different types of agents related to agricultural production (e.g., farmers, landlords). In turn, other key processes of agricultural systems are partially driven by land transactions (Freeman et al., 2009; Happe et al., 2008; Kellermann et al., 2008; Polhill et al., 2005). For instance, the land rental and/or sale market is usually the way that farmers have to expand cropped area. At the same time, agricultural land use tends to be different according to the land tenure regime (Carolan, 2005). As a result, evolving structural changes (e.g., number of active farmers and amount of area operated by each farmer) and land use patterns are closely tied to the dynamics of the land market.

Agricultural systems are complex adaptive systems. Agricultural systems combine the complex biophysical processes of natural ecosystems with the intricacies of human decision-making (Dalgaard et al., 2003). Agricultural systems involve a collection of heterogeneous and autonomous individuals (farmers) interacting with one another and the environment. The farmers are capable of adapting and evolving to perceived changes in their environment. The system-level patterns in agriculture (e.g., structural and land use change patterns) emerge from actions and interactions of autonomous agents and cannot be predicted from examining and

Abbreviations: AACREA, Asociación Argentina de Consorcios Regionales de Experimentación Agrícola; ABM, Agent-Based Modeling; ACE, Agent-based Computational Economics; AL, Aspiration Level; AM, Activity-Management; CAU, Cropped Area Update; CE, Certainty Equivalent; DPR, Desired Profitability Rate; DSSAT, Decision Support System for Agrotechnology Transfer; EU, Expected Utility; GM, Gross Margin; LARMA, LAnd Rental MArket model; LRP, Land Rental Price; MCP, Market Clearing Price; MPR, Minimum Progress Rate; PM, Pampas Model; PR, Progress Rate; WC, Working Capital; WTA, Willingness To Accept; WTP, Willingness To Pay.

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aggregating their individual behavior (Parker et al., 2003). Agricultural markets bear the imprint of the complexity of the system in which they are involved. Accordingly, the dynamics of agricultural markets is determined by the heterogeneity and interactions among agents and their cognitive and sensing capabilities.

Agent based modeling (ABM) is well suited to representing complex adaptive systems such as agricultural systems (Hare and Deadman, 2004; Heckbert et al., 2010; Tesfatsion, 2006). ABM represents the system's component units and their interactions, capturing the emergent system-level properties (North and Macal, 2007). ABM can represent the heterogeneity, bounded rationality, learning capacity and social interactions of the human dimension of complex systems as well as the main properties of the natural components. The increasing use of ABM is associated in part with the recent development of object-oriented programming (Tesfatsion, 2002), that allow a one-to-one mappings between real-world entities and their virtual representations (Rounsevell et al., 2012). The characteristics of ABM make it very suitable to modeling the bottom-up emergent global regularities of economic markets taking place in complex systems. When ABM is applied to computational economics, this approach is often referred to as agent-based computational economics (ACE) (Tesfatsion, 2001b,a, 2002, 2007).

Tesfatsion (2002) defines ACE as "the computational study of economies modeled as evolving systems of autonomous interacting agents." The use of agent-based approaches for modeling markets overcomes some of the restrictive assumptions of traditional quantitative economic models by accommodating bounded rationality, heterogeneity among agents, and out-of-equilibrium dynamics and interactions (Huang et al., 2014; Tesfatsion, 2001a). The existing body of literature has shown the potential of ACE methodology (Tesfatsion, 2001b,a, 2002). Despite the progress that ACE brought to the economic modeling, as we will discuss in more detail below, traditional economic modes may be valid to a large extent to represent some specific markets.

The representation of land markets is an important subfield of ACE. Several land market models that fit in ACE can be found in the literature. Most of the existing studies have focused on urban land use change and housing land market (e.g., Ettema, 2011; Filatova, in press; Filatova et al., 2009a; Filatova et al., 2009b; Huang et al., 2013; Magliocca et al., 2011; Parker and Filatova, 2008; Sun et al., 2014). Furthermore, Filatova (in press) points out that existing models tend to be highly stylized. Much less work has been done in the field of modeling agricultural land markets. Some agent-based agricultural land use change models include land sale or rental market components. For example see the working paper by Kellermann et al. (2008). However, although agricultural production on rented land is widespread in major agricultural areas – more than half of the area is rented in U.S. (Carolan, 2005) or in Argentina (Reboratti, 2010) – there are only few examples showing how to model land rental markets (Berger, 2001; Freeman et al., 2009; Happe et al., 2006). In turn, both for housing land markets and agricultural land markets, there are few assessments of the ability of the models to reproduce the real dynamics of the markets (Filatova, in press).

The contribution of this paper is that it details how to simulate large agricultural land rental markets using a combination of ABM and concepts from traditional economic models. A land rental market in the Argentine Pampas – a major agricultural region – is used as an example. The LAnd Rental MArket (LARMA) model introduced here involves endogenous formation of land rental price (LRP). LARMA fits into the ACE methodology by being integrated into an ABM framework but also applies concepts from traditional economic models. The traditional economic assumptions simplify parts of the design and implementation while the agent-based framework relaxes some of the drawbacks of the traditional economic approach. For example, LARMA allows inclusion of heterogeneous agents interacting with one another. LARMA was designed to realistically represent the Pampas land rental market. The model is run using empirical input data and assessed by its capability to reproduce observed market dynamics (Polhill et al., 2005). This follows an emerging trend in ABM of simulating realistic scenarios rather than stylized modeling experiments (Filatova, in press).

LARMA is integrated into a comprehensive ABM designed to explore structural and land use changes in Argentine agriculture, namely the Pampas Model (PM) (Bert et al., 2011). The purpose of the PM was exploring three main patterns observed in recent decades in the Pampas: (1) an increase in the area operated by individual farmers, accompanied by a concomitant decrease in the number of active farmers; (2) an increase in the amount of land operated by tenants; and (3) an expansion of agriculture, and particularly of soybeans, with the displacement of other crops, pastures, and native grasslands. We have developed the LARMA as part of the PM because of the important role played by land markets in agricultural structural changes and land use (Happe et al., 2008; Polhill et al., 2005).

1.1. Background

The Pampas of central-eastern Argentina is one of the leading cereal and oilseed producing areas in the world (Calviño and Monzón, 2009). Climatic, technological, institutional, and economic drivers have induced significant changes in land use and in the structural characteristics of agricultural production systems in this region (Paruelo et al., 2005). One of the most significant transformations has been a restructuring of land tenure. In recent decades there has been a rapid increase in the amount of land area operated by tenant farmers. At present, as in other parts of the world, agricultural land rental is widespread. Recent estimates indicate that about 60% of the land currently farmed in the Pampas is rented (Piñeiro and Villarreal, 2005; Reboratti, 2010). This means that approximately 13.8 million hectares are currently farmed by agribusinesses that rent land in the Pampas. Considering a land rental price of 450 USD per hectare, representative of the price during the cropping season 2013–2014 (http://www.cadetierras.com.ar/valores-y-estadisticas/valor-alquileres-agricolas/), the size of the land rental market in the Pampas is about 6.2 billion USD per year.

Two main processes have driven the expansion of farming into rented fields in the Pampas. First, small farmers have not been economically competitive under recent economic conditions. Bert et al. (2011) showed that farmers operating small areas (e.g., <200 ha) were unable to generate sufficient income to cover household and production costs. As result, many of them have left active production and rented out their farms (Cloquell et al., 2005; Piñeiro and Villarreal, 2005). These farmers depended for their livelihood on finding jobs at nearby cities (Piñeiro and Villarreal, 2005), and most of them do not return to farming as result of their technical obsolescence and habituation to quasi-riskless rental income. Second, the increasing demand for animal protein and biofuels created a large market for Argentinean grains that raised the interest in agricultural production (Lamers et al., 2008). Simultaneously, the emergence of new technologies (e.g., no-tillage farming and herbicide-tolerant crops) that simplified agronomical management and the implementation of innovative organizational arrangements facilitated by an increasing availability of service providers (e.g., farm labor contractors), enabled significant increases in production scales. This motivated some farmers operating large farms or agribusinesses receiving investments from individuals from other sectors (e.g., from industry or commerce) to expand their production scale (Gallacher, 2010). These emerging large-scale farming firms obtained benefits derived from economies of scale. Due to high land sale prices and a lack of available credit, leasing land became an increasingly attractive alternative to expand production with low transaction costs and limited capital outlays (Swinnen et al., 2006).

The expansion of farming on rented farm was accompanied by a concentration of production (fewer farmers operating larger areas): the average area operated by a farmer increased from around 300 ha in 1988 to almost 500 ha in 2002 in the provinces belonging to the Pampas (Gallacher, 2010). At the same time, the proportion of area farmed by individuals operating less than 200 ha decreased from 64 to 55 % in the same period (Piñeiro and Villarreal, 2005).

Given the history of economic and institutional instability in Argentina, both owners and tenants usually prefer one-year land rental contracts. This implies that at the beginning of each cropping cycle, farmers must actively compete for rental land. A significant proportion of the farmable area is transacted each cycle. Even though tenants often rent the same land repeatedly, they have to negotiate the rental price every cycle. Consequently, immediately after finishing the cropping cycle, farmers must assess their financial status and their expected profits for the upcoming cycle in order to determine their willingness to pay for rental land.

One-year land rental contracts condition a farmer's goals. A number of studies reveal that rented land often is managed differently from owned land (Carolan, 2005; Soule et al., 2000). The differences in goals between landowners and tenants suggest that changes in land tenure may induce new land use patterns. Our examination of farmers' records in the Pampas shows that landowners often follow an ecologically-beneficial rotation of crops. Tenants, on the other hand, tend to maximize short-term profits. As soybeans have been the most profitable enterprise in recent years, this crop has been disproportionately chosen by tenants (Reboratti, 2010; Arora et al. 2015).

Some additional characteristics of the land rental market in the Pampas are relevant for our model design. First, the LRP for a given region and soil quality is well known by most land owners and potential tenants. In fact, farmers who consider moving to an area where they have not previously farmed often can accurately anticipate the LRP in those areas. Second, LRP's for farms in the same region and with the same soil quality are very similar, regardless of farm size (i.e., rental land may be considered a commodity). Third, a large number of agents participate in the rental market (recall that more than half of the Pampas land is transacted every year). Fourth, due to recent high demand and active competition for land, farmers are willing to rent farms relatively distant from their home base, therefore location issues – except for soil quality – are less relevant than in other markets. Fifth, Pampas farmers are market-oriented (i.e., subsistence agriculture is virtually inexistent in the Pampas) and they usually aim to achieve maximum profitability. Finally, land in the study area is privately owned, as the area has been farmed for many decades. At the same time, there is no land abandonment, as land in the Pampas is highly productive (we assume that there cannot be land without farming).

1.2. Overview

In this paper we introduce LARMA and show results from a set of simulations with PM-LARMA. Simulations were aimed to explore the capability of both models for reproducing observed land tenure regimes and market dynamics, and to assess LARMA's sensitivity to a set of uncertain input data and parameters. The paper is organized as follows. First, we provide an overview of the PM. Second, we describe LARMA components and processes. Third, we present and discuss simulation results. The manuscript closes with the main findings that emerged from our efforts to develop a land rental market model.

2. The Pampas Model

A thorough description of the PM following the overview, design concepts, and details (ODD) protocol (Grimm et al., 2010) can be found in Bert et al. (2011). Here we will provide a short summary of the main PM components.

The PM establishes a virtual world representing the northern part of Buenos Aires province near Pergamino. This 10,000 km^2 (1,000,000 ha) area is the most productive subregion of the Pampas, as documented by its long agricultural history (Calviño and Monzón, 2009). The model consists of farmers who make individual production decisions and interact with each other and with their environment. Almost 3100 farmers were active in the target region according to the 2002 National Agricultural Census, the most recent agricultural census in Argentina. Around 1500 of those farmers were owners farming their own land, 1100 owners farming both owned and rented land and 500 farming only rented land. At present, the main crops (i.e., 'activities') in the focus region are soybean, maize, and a wheat–soybean double crop. These three activities together occupied more than 70% of the total land in 2010 (http://www.siia.gov.ar/).

The PM consists of three key entities: the environment, farms, and farmers. The environment is a geographical space containing a number of synthetic farms with a topological relation among them. The number and size of farms is defined at initialization based on data from the 1988 National Agricultural Census. Each farm is assigned a single soil type, and all farms experience the same climate – described by daily historical records from the Pergamino weather station. We assume that the modeled farmers can operate any farm within the target area (i.e., distance to home base is not an issue, a realistic assumption given the limited size of the modeled subregion). The model involves one main type of agent, namely farmers who crop owned and/or rented land, or rent out their land to active farmers. Farmers make decisions based on their prescribed rules, their internal state, their peers' observed outcomes, and the state of the environment. The farmers' decisions can include exiting, reducing, maintaining, or expanding production; determining the portfolio of agricultural activities to grow; and returning to production after leaving. Each agent can have different land allocation strategies, and varying personality (e.g., risk aversion) and financial (e.g., working capital) characteristics. The PM is implemented in the Recursive Porous Agent Simulation Toolkit (Repast) (http://repast.sourceforge.net) (North et al., 2006).

On every cropping cycle, each agent executes a series of steps. At the beginning of a cycle, each farmer adjusts their economic aspirations according to the expected status of relevant contextual factors (i.e., climate conditions, output prices, and input costs). This initial adjustment is part of each farmer's dynamic update of their aspiration level (*AL*) (Diecidue and van de Ven, 2008). Then, the farmer updates the area they will crop, deciding whether to exit, return or stay in production and, in the last case, reducing, maintaining or expanding the previous area. Subsequently, farmers allocate that land among a set of viable Activity and Management options (*AM*), defined by the combination of (1) an activity (i.e., maize, soybean, and wheat–soybean) and (2) agronomic management decisions (i.e., genotype, planting date, and fertilization). After land is allocated, the yield of each *AM* is retrieved from lookup tables built separately using crop models from the Decision Support System for Agrotechnology Transfer (DSSAT) package (Jones et al., 2003). Economic returns are calculated from DSSAT-simulated yields, crop prices, and farm costs specified as model inputs. At the end of the cycle, the working capital *(WC)* for each farmer is calculated as the balance between liquidity from previous cycles and net economic returns from the current cycle. A possible "attainment discrepancy" (Lant, 1992) between economic returns achieved by a farmer and their relevant peers, combined with the farmer's initial aspirations for the cycle drive an adjustment of the farmer's aspiration level (*AL*). The model then moves to the next cycle.

The area to be cropped by each farmer in the upcoming cycle is defined as part of the Cropped Area Update (CAU) module of the PM. The CAU module includes the LARMA model that forms LRP endogenously. In the PM, farmers can only expand their scale by renting additional land. This is a reasonable assumption as renting land is common in the Pampas and selling land is comparatively rare. Other ABM's of agricultural land use sometimes include land market modules. For instance, this is the case of AgriPoliS (Happe et al., 2004) and FEARLUS (Polhill et al., 2010), two models with a purpose similar to our PM. It should be noted, however, that FEARLUS only considers land sales. While all three of these land market models rely at least in part on concepts from traditional economics, AgriPoliS and FEARLUS are based on different auction mechanisms (e.g., first-price or Vickery auctions). This implies individual negotiations among agents that are not present in LARMA but, as will be discussed below, the PM considers interactions between agents nonetheless.

The design of LARMA relied heavily on existing agricultural land markets involved in similar agent-based land use change models (Freeman et al., 2009; Happe et al., 2006). Furthermore, the design of LARMA involved the participation of subject matter experts from AACREA, a farmers' organization partnering in our work (http://www.aacrea.org.ar/). The design of LARMA processes and mechanisms involved an initial revision of existing theories and related models and subsequent interactions with experts to discuss – and eventually modify – model processes and underlying assumptions (Bert et al., 2014). In some cases we modified the existing theory to reflect the way in which experts described reality. This was the case, for instance, of willingness to pay and accept schedules. Here even though we found useful guides in the literature (e.g., Freeman et al., 2009; Magliocca et al., 2011; Parker and Filatova, 2008), the final design corresponded to the descriptions and recommendations of AACREA subject matter experts as described later in this paper.

In the next sections we present details of each stage of the CAU module and the processes involved in LARMA.

3. The Cropped Area Update (CAU) and LARMA

The CAU module of the PM involves three main stages: (1) determination of potential farmland supply and demand followed by formation of an LRP via LARMA; (2) determination of actual farmland supply and demand once LRP is defined; and (3) the actual matching of supply with demand. Fig. 1 shows an overview of the stages in the CAU module.

3.1. Determination of potential farmland supply and demand and formation of LRP

Following the traditional economics approach, we assume that *LRP* results from the equilibrium between supply (i.e., agents who rent out their land) and demand (i.e., agents interested in renting in additional land). Formation of *LRP* by LARMA involves three consecutive steps: (1) the identification of potential supply and demand; (2) the formation of a "willing to accept schedule" (*WTA*) and a "willing to pay schedule" (*WTP*) for each appropriate agent; and (3) the calculation of a market clearance price (*MCP*) representing the *LRP* for the current cropping cycle (Fig. 1). Each step is described below.

3.1.1. LRP formation step one: supply and demand

The first step in *LRP* formation involves the determination of the potential supply and demand of land. During this step, LARMA identifies owners who might have to rent out their farms and agents who could potentially rent additional land. This means that we find those agents who need a *WTA* or a *WTP*, respectively, to make a decision. Note that we refer to *potential* supply and demand because the *LRP* is not yet defined. Therefore, prospective tenants cannot anticipate if their available *WC* will be sufficient to cover rental costs. Further, owners who may consider renting out their farms will base their decision on the *LRP* subsequently formed.

We identify four combinations of farming and ownership. 'Owners-only' farm land that they own. 'Owner–tenants' crop *both* owned and rented land. 'Tenants-only' operate only rented land. Finally, 'landlords' rent out land they own.

Farmers who either lack sufficient *WC* or are unsatisfied with achieved incomes[1] will release previously rented land or rent out their own land. This will add to the overall land supply. An additional source of supply involves land from farmers who have reached the end of their active work life. Similar assumptions are made for the land market component of AgriPoliS, where some of the land available for rent comes from illiquid farmers. For AgriPoliS, the other source is land that is free because either a rental contract has ended or a farm manager has terminated a contract. Farmers with surplus *WC* may be interested in renting additional land and thus contribute to potential demand.

At the start of a production cycle, prior to formation of *LRP*, LARMA assesses each farmer's *WC* to determine if (1) landlords can return to active farming, (2) farmers can maintain their cropped area, (3) farmers can expand production by renting additional land, or (4) farmers must release some or all previously farmed land. This assessment depends on each farmer's ability to cover likely planting costs (e.g., labor, seeds, and agrochemicals) for the most expensive *AM* and estimated rental costs for rented farms. Table 1 lists the types of farmers who need to form a *WTA* or a *WTP*.

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 will no longer be available to previous tenants. Two mechanisms are available to allow landlords to return to active farming: (1) a constant probability of return, 25% by default and (2) a probability of return that decreases with time and becomes zero after six cycles. The first mechanism reflects the low real-world proportion of landlords that actually return to farming, as landlords tend to develop expectations for steady rental incomes with minimal risk. The second mechanism represents the atrophying farming skills of inactive farmers.

After dealing with landlords, the model assesses the ability of remaining active farmers to operate a certain area. For landowners, even when they have sufficient *WC* to continue operating their farms, they assess whether they are satisfied with their economic progress in the recent past. The assessment of satisfaction implies two steps.

First, a farmer computes their economic progress rate (PR) over the *M* most recent cropping cycles – PR is defined as the relative variation in WC between two consecutive cycles. Second, the farmer compares this PR to a target Minimum Progress Rate (MPR) that is the minimum of two alternative values: (1) an MPR defined for each farmer at initialization (e.g., 5%) or (2) the average PR of the

[1] We discuss unsatisfied farmers at the end of this subsection.

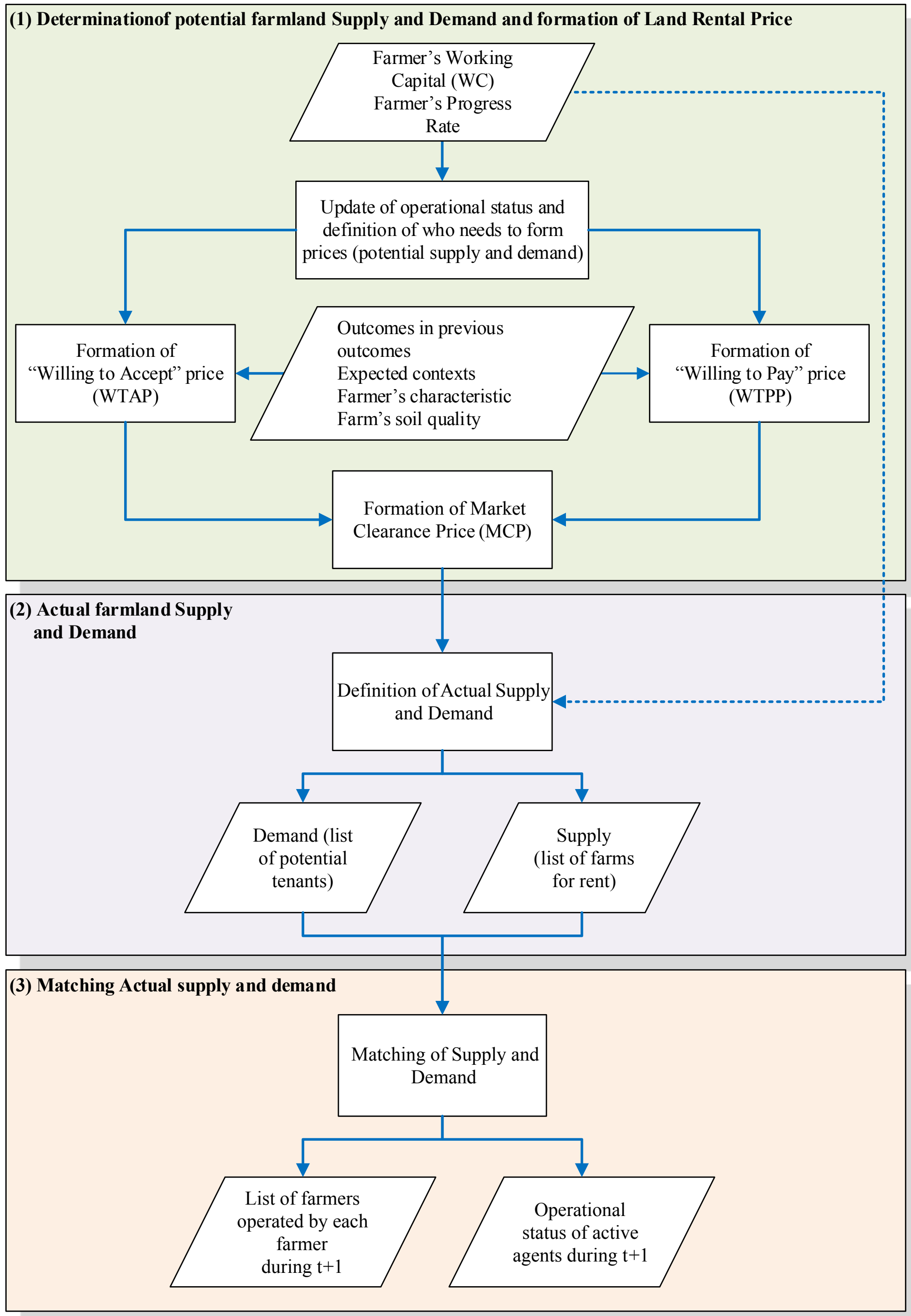

Fig. 1. Overview of the stages and main processes involved in the CAU module of the PM.

Table 1
Summary of agents who need to form a WTA and a WTP on a given cropping cycle. Agents may have different land tenure status on each cycle.

Who needs to form *WTA*?	Who needs to form *WTP*?
1. Landlords who do not have sufficient *WC* to return to active farming 2. 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
1. Owners-only who do not have sufficient *WC* to continue operating their farms 2. 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 their land)	Owner–tenants who have sufficient *WC* to continue operating their farms
	All tenants-only

farmer's spatial neighbors. This second option was defined to avoid considering as unsatisfactory cycles with low economic returns that arise from unfavorable contexts (e.g., poor climate conditions) affecting all farmers similarly. If the farmer's PR is higher than their MPR in *N* out of *M* cycles, the farmer is satisfied. Otherwise, they are unsatisfied and will consider renting out their farm. Consequently they need to form a WTA. As discussed below, this farmer will actually rent out their land only if the formed *LRP* is higher than their *WTA*.

When both active landowners and tenants are unable to operate a given area due to financial constraints, then they must exit (i.e., release rented farms and/or rent out their own farms; Table 1).

3.1.2. LRP formation step two: WTA and WTP

The second step in LRP formation involves the calculation of a *WTA* and a *WTP*. A *WTA* is the minimum price that an owner is willing to accept to rent out their farm. We assume that an owner's *WTA* is based on an estimation of the profits that they could achieve from operating their farm. Note, however, that profits from crop production are inherently variable and risky. Risky production incomes and the virtually guaranteed income from renting land must be compared on an equal, risk-free basis. Thus, three calculations are required to form a *WTA*. First, LARMA computes the expected utility (*EU*) of a set of *m* possible *AM*s in *n* recent cycles. Note that *m* and *n* are model input parameters. We will refer to these as the 'proportion of best AMs' and 'N cycles' respectively. The proportion of best AMs indicates the proportion of all AMs (sorted in decreasing order of economic outcomes) that are used in the computation of EU. This is an estimation of the results that the owner could achieve from operating their farm, albeit with risk. Second, LARMA calculates the certainty equivalent (*CE*) of the *EU*, to transform the risky production outcomes into guaranteed, although potentially less valuable, outcomes. Finally, the WTA is computed by adding to the *CE* the structural costs that must be paid by the farm's owner and subtracting those that must be paid by the tenant. Details of the WTA calculation are given in the Appendix.

A *WTP* is the maximum price that a potential tenant is willing to pay to rent a farm. We assume that a prospective tenant's *WTP* is based on the economic gross margin (*GM*) they expect to achieve during the upcoming cycle. We also assume that the target *GM* is equal to the farmer's *AL*, which in turn is adjusted by the expected status of context factors. Note that the context-adjusted *AL* weaves together a farmer's own experience, a farmer's observations of their neighbors' experiences, and a farmer's expectations about the future (Lant and Shapira, 2008). We assume further that a farmer seeks a minimum return rate (i.e., model parameter *r*; also named 'desired profitability rate' or DPR) for the capital that they must commit at the beginning of a cycle. A similar concept is used in AgriPoliS, which uses a parameter (β) equivalent to our DPR. This capital, which we refer to as committed capital (*CC*) includes all fixed direct costs (i.e., seeds, fertilizer, labor, etc.) and land rental costs. In other words, we assume that potential tenants seek to obtain a net margin (*NM*; *GM minus Indirect costs*), or revenue, based on their *CC* and *r*. Details of the WTP calculation are given in the Appendix.

We assume that a farmer can only calculate *WTP* for the soil types they have operated in the previous cycle. If a farmer has operated various farms with different soil types, then they will calculate a separate *WTP* for each soil type (note that *GM* may change for different soils). When the potential tenant assesses renting a new farm with a soil type different from that they cropped in the previous cycle, we assume that the farmer does not compute *WTP* and accepts the corresponding *LRP* defined by the market. Transportation costs influence farmers' biddings in other models (e.g., AgriPoliS) although not in LARMA, as we assume no differences in the distance to port within the target area.

3.1.3. LRP formation step three: MCP

The third step in LRP formation is the determination of an MCP. In LARMA, the MCP represents the LRP at which the quantity demanded and quantity supplied of land area for rental are equal. To begin computing the MCP, a list is built with all WTA and WTP values. This list represents possible market prices (MP). For each MP, LARMA assesses the total number of hectares that could be rented by potential tenants at that price. The area that each potential tenant could rent is the ratio of their surplus WC and WTP. This area is summed for each MP over all tenants for which WTP $\geq$ MP. Next, the total number of hectares that would be rented out by owners at that MP is determined. The total area that would be rented out at a given MP is calculated by identifying landowners for whom MP $\geq$ WTA and then adding up farm areas for those owners. This process is repeated for supply and demand at each MP. Once both the supply and demand curves have been constructed, the MCP can be found at their intersection (i.e., the MP that maximizes the area transacted). Fig. 2 represents the main processes of MCP formation.

3.2. Actual farmland supply and demand

The second stage in the CAU module involves the definition of actual supply and demand of farmland for the current cropping cycle. Some of the farms and farmers included in the actual supply and demand curves were identified in the previous stage. However, not all of these farms and farmers will actually enter the market. All tenants need an actual *LRP* before deciding whether they can maintain their previous rented area or expand. Tenants with insufficient *WC* must release some rented area (tenants start releasing the smaller farms), and this land is added to the actual supply. Further, owners who have sufficient *WC* to remain active but are unsatisfied with their economic progress will choose to rent out their land only if *LRP* $\geq$ *WTA*. Consequently, actual supply is defined after including farms released by tenants with insufficient *WC* and excluding unsatisfied owners with WTA $\geq$ LRP.

3.3. Matching actual farmland supply and demand

The final stage of the CAU module matches actual supply and demand to determine the area that each agent will crop. Fig. 3 shows details of supply and demand matching. 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 rent and selects suitable choices. First, they exclude farms that they cannot afford (i.e., too large). Second, they exclude farms that are too small[3] to be of interest. This represents the empirical fact that farmers operating relatively large areas generally do not consider renting very small farms. Once a farmer rents a farm, or passes, they are returned to the list of potential tenants if they have remaining *WC*. Otherwise they are deleted from the list of candidate tenants. Next, another farmer is randomly selected from the list and the farm selection process is repeated. The process ends when all farms have been rented. If farms remain available after all potential tenants have been

[2] The probability of being selected is proportional to the potential tenant's *WC*. This reflects 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.

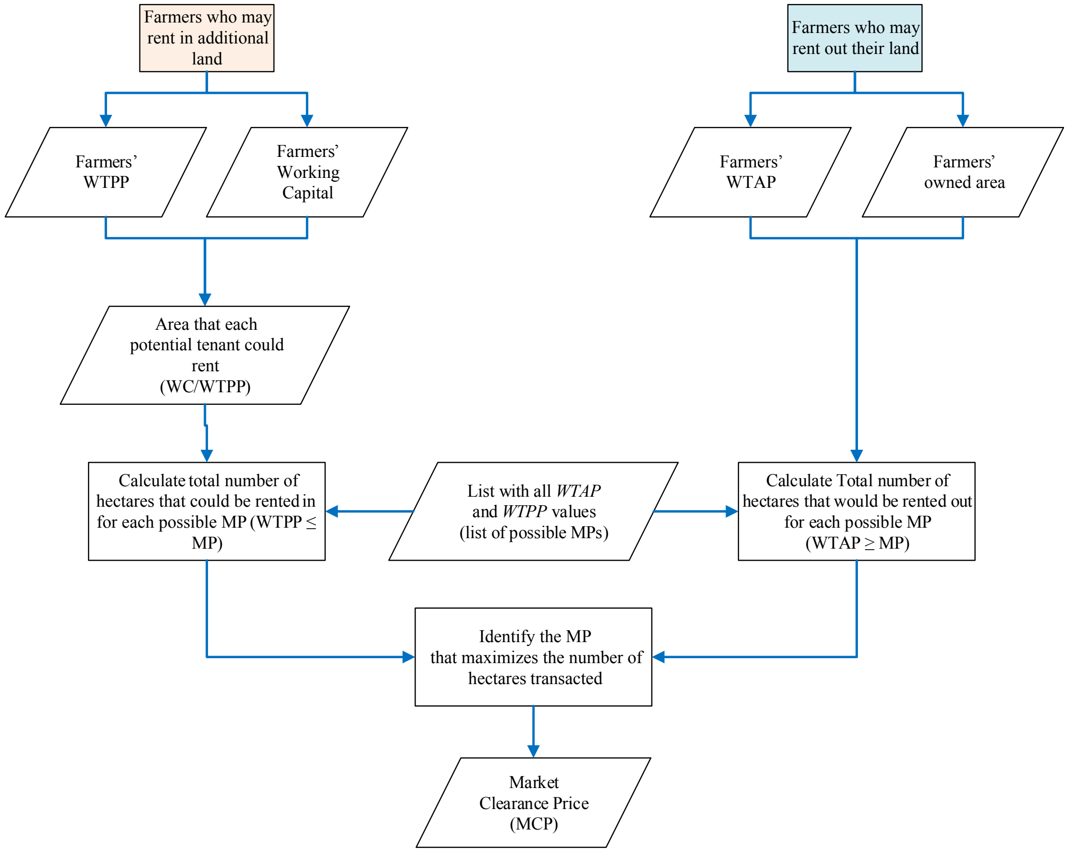

Fig. 2. Overview of the main processes involved in the calculation of the MCP.

exhausted, previously inactive agents created at initialization are assigned to a farm and given sufficient *WC* to operate that farm.

LARMA assumes that all land rental contracts have a fixed duration of one year. This is a realistic assumption for the Pampas. However, we assume that the current tenant has priority to continue operating a farm. If the tenant has sufficient *WC*, they re-rent their current farms (at the LRP defined by the market) and these farms are not added to the list of land for rent. This is also a reasonable approach, as the majority of contracts are renewed between the same individuals.

4. Simulations

4.1. Simulation details

We ran a set of simulations using the version of the PM described by Bert et al. (2014). The simulations represented the northern Buenos Aires region during the period 1988 to 2009. We started simulations in 1988 because the National Agricultural Census conducted on that year provided most of the information needed to initialize the PM. Model initialization procedures were designed to ensure that (1) the distribution of simulated farm sizes, (2) the number of farms, farmers and total area operated by each farmer, (3) land use, and (4) the proportion of area operated by owners and tenants were all consistent with data from the 1988 Census. Table 1 in Bert et al., 2014 summarizes the initial (1988) values assigned to each of these variables.

A *baseline scenario* was executed using realistic trajectories for PM input variables and nominal parameter values derived from Bert et al. (2014). Furthermore, 16 additional scenarios were executed to assess the model sensitivity to changes in input data series and parameter values closely tied to LARMA. Each scenario assumed a particular combination of: (1) trajectories of input data, and (2) agents' parameter or attribute values. Table 2 provides details about the values tested for the input data and PM parameters. Although we are aware that model sensitivity may be different when two or more variables change simultaneously, each of our sensitivity analysis scenarios varied only one variable at a time. We chose this path because we sought an initial characterization of the model's sensitivity to its inputs.

4.2. Analysis of simulations

The analysis of simulation results was focused on aggregated land tenure regimes and the dynamics of the land market. Many of the comparisons performed in this paper for validating land market models follow those suggested by Polhill et al. (2005).

We assessed the model's ability to reproduce observed land tenure changes. To this end, we compared simulated changes in the area operated by owners and tenants against data from 2002 National Agricultural Census (the most recent census) and from local reports for the recent years. We also explored the impacts of input data and parameters tied to LARMA on the simulated land tenure patterns.

Most importantly, we assessed LARMA's ability to reproduce the dynamics of LRP, a key variable that integrates the whole behavior of the land rental market. To this end, simulated LRP's were compared against reported values. This is a valid comparison in the context of the study region because: (1) the spatial heterogeneity in soil quality is relatively low (i.e., two soil types cover more than 80% of the cropped area) and (2) LRP's are essentially the same for farms with similar agricultural potential. The comparison between

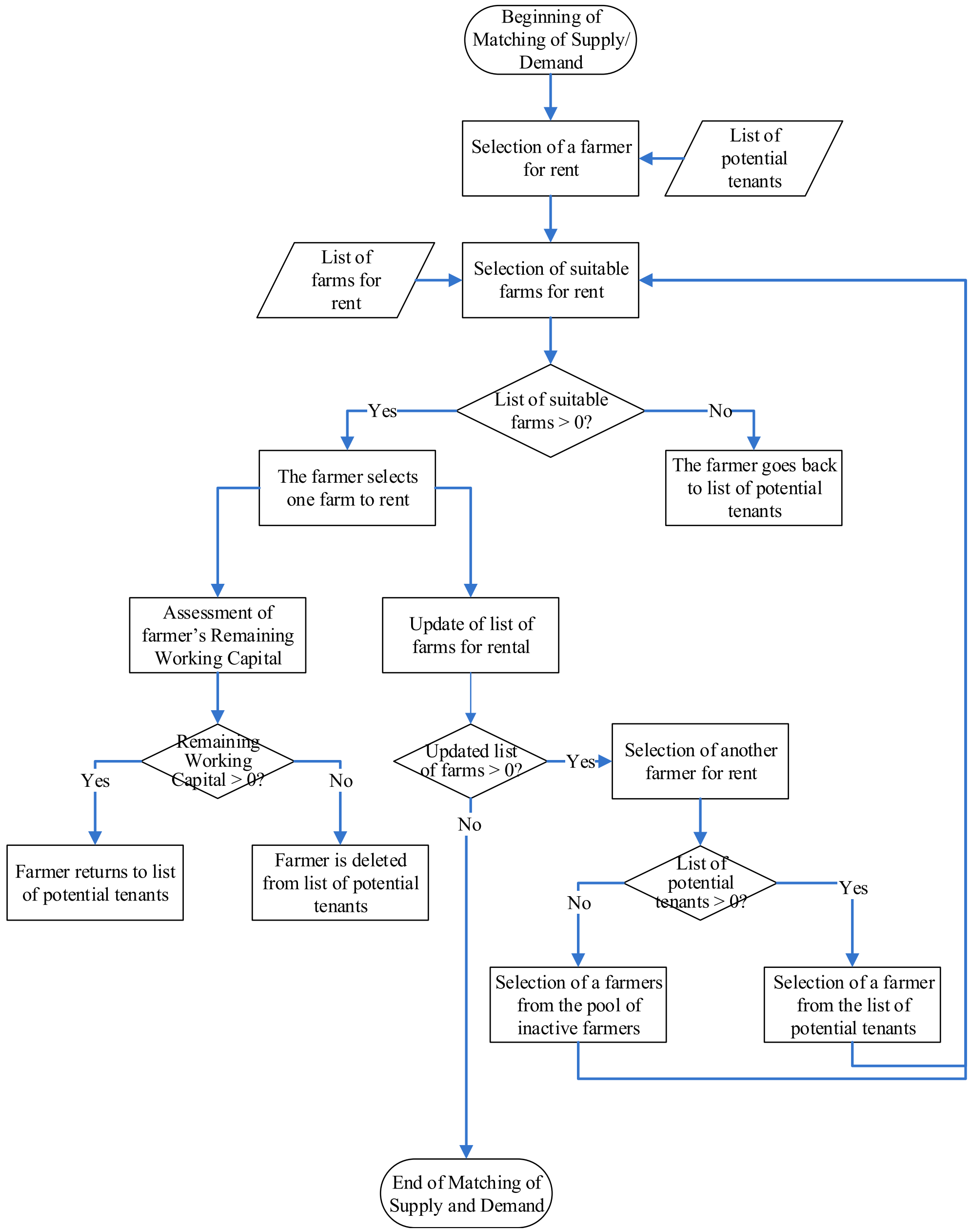

Fig. 3. Overview of the main processes involved in the matching of supply and demand.

simulated and observed prices under the various scenarios was also useful to explore the correctness of nominal parameter values and, eventually, identify alternative values. We computed two main metrics to assess the fitness of simulated prices: (1) Ordinal pattern analysis (OPA) (Thorngate and Edmonds, 2013) and (2) root mean square error (RMSE). We also explored other relevant variables computed by LARMA, including supply and demand volume and WTP and WTA values. Unfortunately, no comparison with observed values was possible for these variables because of the lack of available data.

Land rentals are paid in monetary terms ($\$ \text{ ha}^{-1}$) in Argentina. However, the LRP is usually agreed in tons of soybean per hectare (tons ha^{-1}). Accordingly, the total amount that the tenant pays or the landlord receives for land rental depends on (1) the tons of soybean per hectare agreed and (2) the soybean price (tons $\text{ha}^{-1} \times \$ \text{ ton}^{-1}$). The soybean price in Argentina is determined by the global soybean market and the local export taxes (35%). The influence of Argentinean soybean production on the global soybean price is very low, as Argentina only produces 16%–18% of global production (http://faostat.fao.org/). The comparison of simulated against reported LRP's was made in monetary terms as the records available were expressed in those units (data on LRP's in Argentina are scarce).

We gathered LRP information from: (1) a trade magazine, *Márgenes Agropecuarios*, (http://www.margenes.com/) that published LRP's for the period 1995–2010 and (2) a real estate firm (CAT, http://www.cadetierras.com.ar/) that reported prices for 2001–2010. There were considerable differences in the prices reported by both sources for some years. We hypothesize that these differences may be related to: (1) the time of the year for which the price was reported (LRP's in tons of soybean per hectare may vary within a year in response to changes in context factors) and (2)

Table 2
Description of the input data and parameter values tested in the sensitivity analysis.

Input/parameters	Description	Values explored	OPA	RMSE	Description/meaning
Input data					
Gross margin (GM)	Gross margin ($/ha) of agricultural activities considered in the model	Observed series	0.096	79.9	Observed values reported in *Agromercado* magazine (1983–2010)
		Constant average values	0.049	94.5	Median values for each activity from 1983 to 2010 repeated along the simulated window
		Random values	0.119	95.1	Gross margin series built from random resampling of values without replacement
Status of context factors	Expected and actual status (i.e., unfavorable, normal and favorable) of context factors (i.e., climate, output prices, and input costs)	Realistic series	–	–	Realistic values defined based on available records of rain, output prices, and input costs Expected climate is always normal (i.e., there is no forecast), Expected and actual status of input costs are the same
		Constant values	0.119	95.1	Normal expected and actual status for all factors and cropping cycles
		Random values	0.372	106.3	Random resampling of years without replacement and reordering of the series of expected and actual statuses according to the new order
Parameters					
Desired profitability rate (DPR)	Profitability rate from the committed capital sought by potential tenants (for use in WTP formation)	10%	–	–	Potential tenants seek average profitability
		5%	0.061	93.97	Potential tenants seek low profitability
		15%	0.071	85.13	Potential tenants seek high profitability
Lambda up/down	Parameter involved in the AL adjustment for the next cycle that reflects the inertia to change AL by weighting recent achieved margins and previous AL's (see Bert et al., 2011).	0.45/0.55	–	–	Farmers adjust AL based on both recent achieved margins and previous AL Lower values for lamda up reflect the fact that people acclimate to higher payoffs more rapidly than to lower ones
		0/0	0.075	85.5	Farmers adjust AL based only on recent achieved margins
		1/1	0.633	130.8	Farmers adjust AL based only on previous AL
Proportion of best AMs	Proportion of the total possible activities and managements that the owner considers during WTA formation	100	–	–	Owners consider all possible AMPs
		20	0.072	81.73	Owners consider the top 20% of AMs based on margins
		50	0.072	84.44	Owners consider the top 50% of AMs based on margins
N cycles	Number of previous cropping cycles considered by owners while forming WTA's	3	–	–	Owners consider last three cycles
		1	0.157	88.34	Owners consider only last cycle
		6	0.073	77.33	Owners consider last six cycles
Peer adjustment factor	Used in the calculation of AL's. It defines how strongly peers' margins influence the farmer's assessments of their own margins. The farmer adjusts their margin by weighting the average margin of peers and their own margin according to this factor.	0.5	–	–	Peers' margins have a high influence
		0	0.082	78.8	Peers' margins have no influence
		0.25	0.097	79.0	Peers' margins have a moderate influence
Heterogeneity in DPR	DPR values initialized to agents	0.1	–	–	All agents are assigned with the same DPR value
		0.05–0.15	0.069	83.53	Agents are assigned with a random DPR value sampled from a uniform distribution from 0.05 to 0.15

within-cycle changes in soybean price. Given the limited availability of observed prices and the apparent inconsistencies in available data, we computed an average LRP using both sources listed (when both were available); a range of potential prices was estimated as fixed relative deviations (±15%) from the average value.

5. Results and discussion

5.1. Land tenure

We previously reported that the PM has reproduced appropriately the observed changes in land tenure in the Pampas (Bert et al., 2014). Specifically, the simulated proportion of area operated by tenants increased from 37% at the beginning of simulated period to more than 50% at the end of the simulation (Fig. 4). These results are consistent with data from agricultural censuses and recent reports (Reboratti, 2010). Simulated land tenure patterns emerge from land transactions between agents simulated by the CAU module and the LARMA within the CAU.

The inclusion of the LARMA model within the PM was critical for reproducing observed land tenure changes. Results from a scenario with exogenous LRP's (e.g., a constant average price for the entire simulated period), led to significantly lower proportions of rental land area compared to the baseline scenario. Specifically, the simulated proportion of area rented was 38.0% in 2001 and 41.9% in 2009 with exogenous formation of LRP's, while it was 44.4% in 2001 and 51.5% in 2009 with endogenous formation of LRP.

Finally, the LARMA model produced valid outcomes for a wide range of parameter values. For example, varying the PM land market parameters in the ranges shown in Table 2 did not change significantly the simulated aggregate output patterns (Fig. 4).

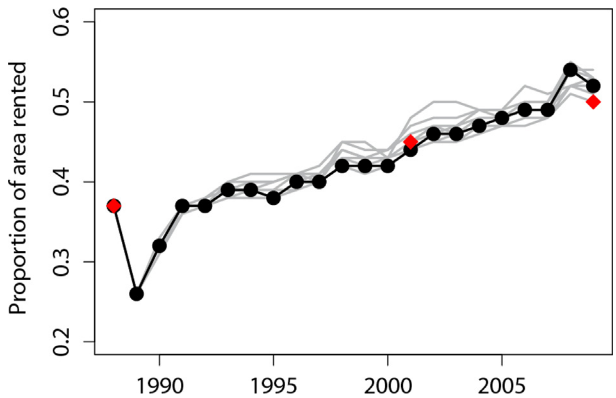

Fig. 4. Proportion of area rented in the nominal scenario (black line with circles) and scenarios aimed to assess model sensitivity to six key parameters tied to the land rental market (Table 2). The red rhombuses represent observed proportions of rented area in national agricultural censuses. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

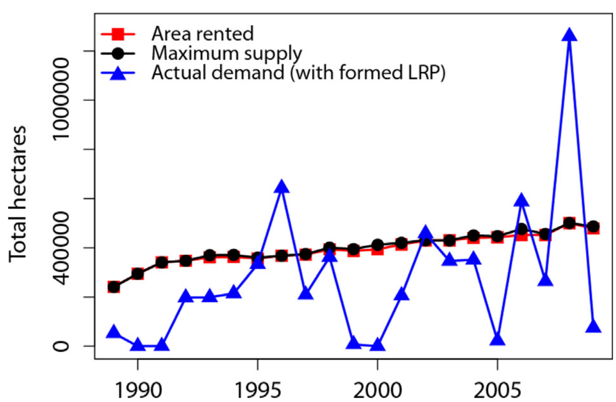

Fig. 5. Maximum area supplied (black line with circles), actual area demanded (sum of area that would rent those potential tenants for whom the WTP is greater than the formed LRP) (blue line with triangles), and simulated proportion of area rented (red line with squares). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The growing proportion of area operated by tenants is strongly driven by increasing land supplies during the entire simulated period (Fig. 5). The increasing supply of land was mainly driven by (1) the exit of farmers owning small areas (e.g., less than 200 has) as these farmers are economically unviable in the long run and eventually must lease out their land; and (2) the exit of farmers reaching retirement age without heirs who choose to continue running the family farm.[4] The farms released are added to the land supply and then rented by owners with surplus WC, often those operating medium to large areas (Bert et al., 2014). In turn, the land area demand showed significant inter-annual variability (Fig. 5). This variability was linked to the financial status and income expectations of potential tenants. Although the potential demand, assuming the formed LRP's, is low for particular years (i.e., there is a significant proportion of potential tenants for whom WTP is less than the LRP), the sum of WC over all potential tenants was sufficient to rent 4.8 to 14.4 times the total area supplied. In summary, our results show that the total area rented during the simulated period was mainly conditioned by the available land supply and there were no practical limitations of capital on the demand side.

[4] The PM addresses economic viability but not retirement without available heirs.

5.2. Land rental price

LARMA accurately reproduced the dynamics and levels of land rental prices in the period under study (Fig. 6). The OPA analysis showed that the dynamics of prices simulated in baseline scenario were similar to the behavior of observed prices as indicated in Table 2. The RMSE analysis shows a close association between simulated and observed prices with the RMSE being about 25% of the mean LRP's (Table 2). Two key historical events are remarkably well reproduced by the model, namely the drop in rental prices observed after: (1) the fall of record-high commodity prices in the late 1990's and (2) the strong drought during 2008–2009 cropping season (Skansi et al., 2009). These milestones were distinctly identified by experts from a farmers' organization (AACREA) during a meeting aimed at discussing the PM and LARMA assumptions and results.

The closeness between observed and simulated rental prices suggests that LARMA represents the main processes and captures the essential behaviors of the land market in the Pampas. The realistic model structure resulted from both using well-understood and accepted agent-level theories for calculation of willingness to pay and accept prices and the active involvement of experts and stakeholders from the study area in LARMA development. Input from local experts was particularly helpful for defining assumptions about both the formation of willingness schedules and rules for identifying potential tenants and landlords (Bert et al., 2014).

Fig. 7 shows the distributions of WTA's and WTP's and the formed LRP for each cropping cycle of the baseline scenario. As WTA and WTP are computed based on the agents' individual status and preferences, there is considerable heterogeneity in the prices formed. This heterogeneity influences the shapes of the supply and demand curves and, therefore, the LRP. In some particular cycles (e.g., 2000) there are marked differences between the WTA and WTP distributions and, consequently, a lack of fit between supply and demand is observed. In these cases, a central LRP is computed by averaging across all WTA and WTP values. Note that the proportion of cases without matching is relatively low (only 2 out of 21 cycles). This high level of matching is particularly interesting given that WTA and WTP are formed by independent mechanisms (Parker and Filatova, 2008).

5.3. Sensitivity analysis

We explored the model sensitivity to: (1) two key PM input variables and (2) a set of PM parameters related to the land rental market. In the next sections we present the main results from the sensitivity analysis.

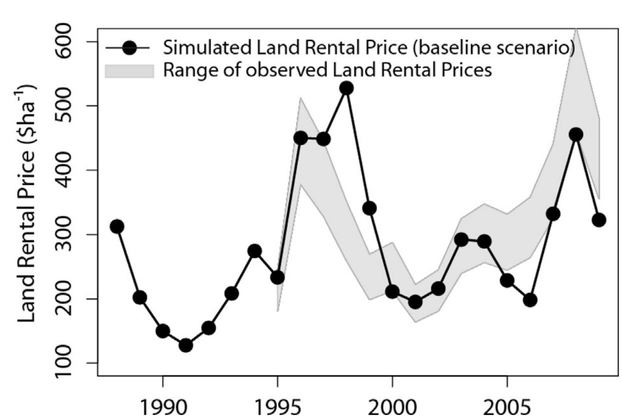

Fig. 6. Range of observed and simulated LRP's for the baseline scenario.

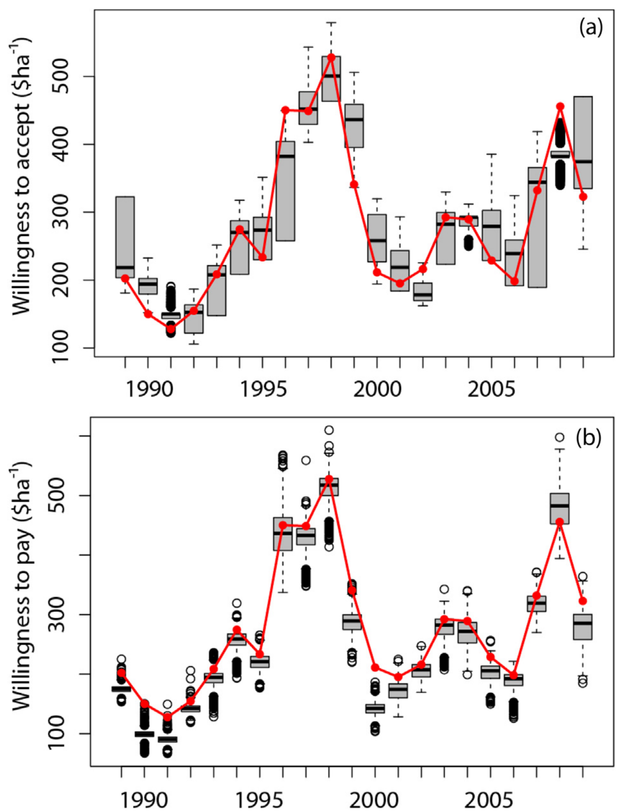

Fig. 7. Boxplots of: (a) WTA and (b) WTP for the baseline scenario. The red line with circles in both figures shows the formed LRP. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

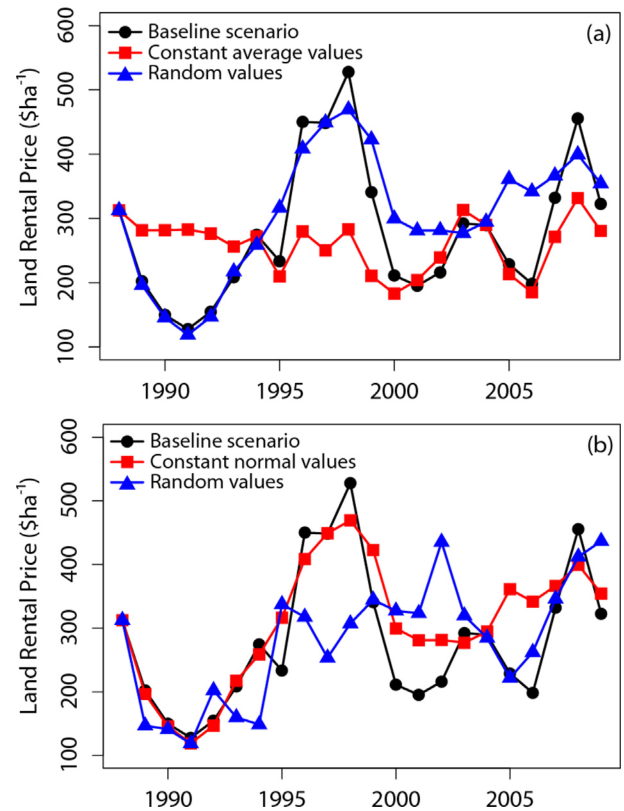

Fig. 8. Sensitivity of LPR to changes in two key PM input variables: (a) gross margins of alternative agricultural activities and (b) expected status of context factors.

5.3.1. Input data

The trajectory of simulated LRP's was extremely sensitive to two model input variables, namely (i) the expected status of context factors and (ii) the gross margins of alternative agricultural activities. Both WTA and WTP formation depends on these variables, as discussed in Section 4. LRP's simulated for scenarios with constant or random, but approximately average, context factors and gross margins deviated significantly from observed LRP's, as shown in Fig. 8a and b. The contrasts between the simulated and observed LRP's also are reflected in the OPA and RMSE metrics in Table 2. Thus, realistic expected context factors and gross margins were required to reproduce the observed market dynamics.

Simulations show that context factors and gross margins are equally relevant to simulate land prices in the Pampas. Even assuming a highly unusual trajectory for one of the variables – such as a random path – and keeping the other variable at realistic values produces simulated LRP's that are not completely uncoupled from the observed values. For example, using random gross margins for AM's and realistic values for the expected status of context factors (Fig. 8a) yielded LRP results (Table 2) that partially follow the values in the baseline scenario. This suggests that both past results (e.g., farmer's gross margins in the previous cycle) and expectations for the upcoming cycle are key drivers in the formation of land rental prices in the Pampas.

5.3.2. Parameter values

The various model parameters explored did not substantially modify the aggregated land tenure outcomes as indicated in Fig. 4. However, different parameter values led to noticeable changes in simulated LRP's. Depending on the parameter, the parameter ranges explored led to variations in both the dynamics and the level of LRP's.

The desired profitability rate (DPR) is a key parameter for the computation of a potential tenant's WTP (see discussion in Section 3). Because this parameter refers to a desired profitability, the lower limit is zero (i.e., a farmer would not seek to lose money). Although there is no maximum, it would be unrealistic to assume return rates >20–30%. The baseline scenario assumed a nominal DPR of 10%. Simulation outcomes show direct impacts of DPR values on LRP's as indicated in Fig. 9a. Higher DPRs lead to lower WTP's (data not shown) and, consequently, lower LRP's. If a farmer is seeking higher profitability then, everything else being equal, they need to pay less to their landlord. A DPR of 5% slightly increased LRP's and brought the simulated results closer to the observed outcomes.[5] However, subject experts from AACREA considered the value of 5% too low for a risky activity such as agriculture.

Lambda is a key parameter of the dynamic AL adjustment described in Bert et al. (2011) and references therein. The AL is involved in the formation of WTP as discussed in Section 3. The farmer's AL depends on the initial AL and the economic results achieved in the previous cycle. The lambda parameter weights both terms, reflecting the resistance or inertia to adjusting the initial AL according to the achieved economic results. The lambda parameter may range between 0 and 1. When lambda is zero, the adjusted AL is equal to the initial AL. When lambda is one, the adjusted AL is equal to the achieved economic result. Further, we distinguish between the upward and downward use of lambda because the

[5] Note in Fig. 4 that simulated prices are slightly below the observed ones during the last years under study, which is not the typical arrangement seen in the other data.

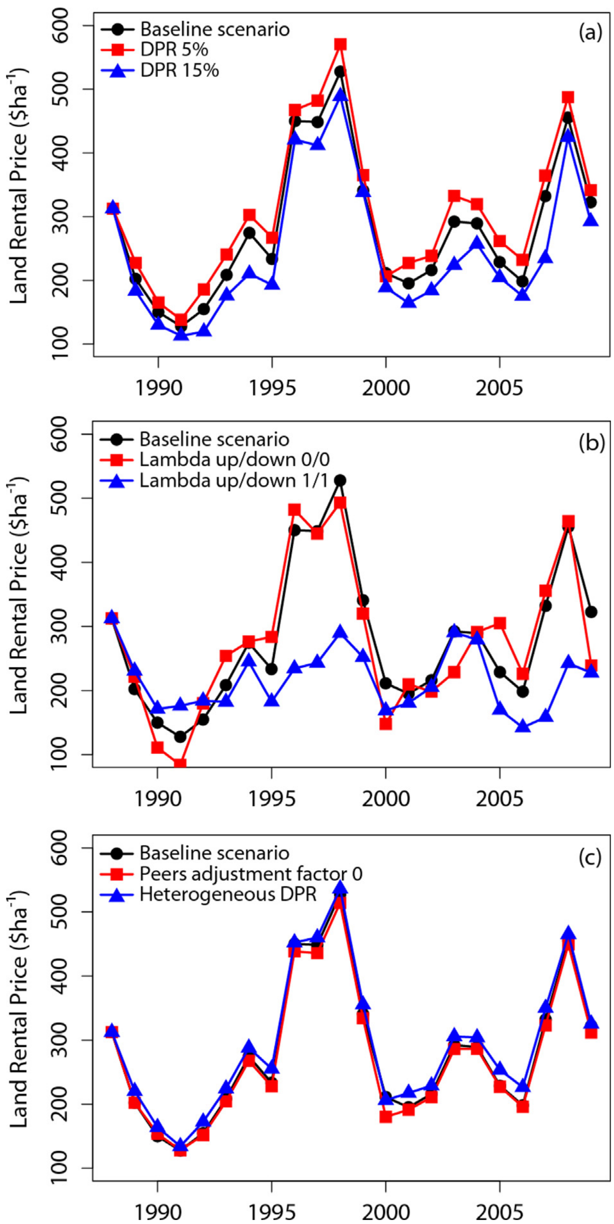

Fig. 9. Sensitivity of LRP to changes in PM parameters values related to the land rental market. Figure (a) shows LRP's for simulations changing the value of desired profitability rate (i.e., identical changes in parameters for all farmers). Figure (b) shows LRP's for simulations changing the value of lambda (i.e., identical changes in parameters for all farmers). Figure (c) shows LRP's for simulations changing the value of peers adjustment factor (i.e., identical changes in parameters for all farmers) and for a simulation in which agents were assigned heterogeneous values from 0.05 to 0.15 of the desired profitability parameter.

resistance to increasing AL is lower than that for decreasing AL (i.e., people acclimate to higher payoffs more easily than to lower ones). The baseline scenario assumed nominal lambda values of 0.55 and 0.45 for upward and downward adjustments respectively. Model runs demonstrate that extreme lambda values have a significant impact on the dynamics of LRP's as shown in Fig. 9b and the OPA values in Table 2. The most significant effects appeared when lambda was one. This result stresses the relevance of economic results for aspiration adjustment and, in turn, the relevance of AL for the WTP calculation.

The ‘proportion of best AM's’ parameter is used in the calculation of WTA as discussed in Section 3. This parameter sets the proportion of all AMP's (sorted from highest to lowest economic results) that the landlord considers when estimating possible outcomes from farming their land. The proportion of best AM's should be greater than zero and less than or equal to one. When this parameter nears zero, the landlord only considers AM's with the highest economic results to calculate WTA. Conversely, when this parameter nears one, the landlord considers all AM's to calculate WTA. The baseline scenario assumed a nominal value of 1. The range of values tested increased WTA as owners formed prices considering only some proportion of top AMPs. However, the increases in WTA did not translate into increases in LRP's.

The ‘N cycles’ parameter is used in the calculation of WTA as detailed in Section 3. This parameter sets the number of previous cycles that the landlord considers to estimate possible outcomes from farming their farms and, consequently, to calculate WTA. The lower limit for this parameter is one year. There is no upper limit, but to maintain realism we assumed a maximum value of six years to reflect limited memories. The ‘N cycles’ parameter did not have a significant impact on LRP's. The ‘N cycles’ values tested modified the WTA, but this effect was not reflected in the LRP's. However, WTA variations were smoother when this parameter was set to the maximum value of six.

Finally, previous paragraphs have described effects of simultaneous changes in parameter values for all farmers. However, as LARMA is embedded within an agent-based model, it can simulate heterogeneous agents interacting with one another. For this reason, we also explored the impact of agent heterogeneity on the dynamics of the land rental market.

We explored agent heterogeneity using a model parameter that had a substantial influence on simulated LRP's, namely DPR. We randomly assigned DPR values to agents using a uniform distribution ranging between 0.05 and 0.15.[6] The heterogeneity in DPR did not have a significant impact on LRP's as shown in Fig. 9c. The heterogeneity in this parameter changed only slightly the distributions of WTP's, but the effect was not propagated to LRP's.

The PM considers direct interactions among agents during the adjustment of agents' AL's. Before defining the AL for an upcoming cycle, the agents compare their achieved results with their peers' achievements. If peers achieved a higher average result, then the farmer adjusts their expectations by weighting their own outcome and the peers' achievements. The weighting parameter is the ‘peer's' adjustment factor,’ that ranges between 0 and 1. A value of 0 means that the agents adjust their AL based only on their own achievements. Correspondingly, a value of 1 indicates that the agents adjust their AL based only on their peers' achievements. The range of values explored slightly modified the distributions of WTP's. A wider distribution of WTP values was observed when the factor was zero as consequence of the lack of interactions between farmers. However, the effect of changes in peer's adjustment factor was not translated to LRP's.

6. Lessons learned

We now discuss four meaningful lessons learned from our experience introducing an agricultural land rental market model into an agent-based model. We hope these insights may help others undertaking similar tasks.

First, adaptive agents are required to obtain realistic representation of extremely dynamic markets such as the Pampas land rental market. The PM involves two adaptation mechanisms. First, agents change their cropped area according to their WC (e.g., an

[6] Please note that the mean value is equal to the nominal value assumed in the baseline scenario.

agent may release previously leased land if they do not have sufficient WC, or may rent additional area if they have surplus WC). Second, the agents adapt dynamically their economic aspirations (AL). The AL drives the formation of agents' WTP, and ultimately LRP's, according to the interplay of expected and achieved economic outcomes. ABM's offer the opportunity for considering adaptive agents that make decisions according to their current status, previous experiences and perceptions of the context. This was critical to successful modeling of land tenure changes (e.g., farmers with surplus WC that expand production by renting additional land) and the dynamics of LRP's in the Pampas (e.g., tenants who form lower WTP as consequence of unfavorable outcomes in the preceding cycle).

Second, agent heterogeneity is necessary to reproduce market dynamics and emergent land tenure patterns. In the PM, the same set of rules may lead to very different market decisions depending on each agent's status. Consequently, farmers may evolve heterogeneously. For instance, after an unfavorable cycle (e.g., a dry cropping season), farmers operating small areas (e.g., areas < 100 ha) may have to exit farming and rent out their farms. Conversely, farmers operating large areas may have enough savings to continue cropping the same area or increase this area by renting in additional land, even following adverse conditions. Assuming every market participant is an 'average or representative farmer' does not properly represent this heterogeneous behavior. Agents also may have heterogeneous preferences (e.g., DRP). In LARMA, heterogeneity in individual preferences may affect WTA and WTP, and ultimately LRP. However, we only found subtle differences in LARMA results when the agents were initialized with heterogeneous DPR values. The capability of ABM's to consider agents that may evolve heterogeneously was critical to successful modeling land tenure changes and market dynamics in the Pampas. The relevance of considering heterogeneities in preferences may be higher for markets where the agents have contrasting goals[7] and/or the goods transacted have amenities and disamenities associated to spatial variations (e.g., Filatova, in press; Filatova et al., 2009b; Huang et al., 2013).

Third, interactions between agents may be critical to reproducing land rental market processes. The PM considers interactions among agents during individual AL adjustment. Here, we found that the strength of interaction between agents, quantified by the peers' adjustment factor, slightly changed aggregated land tenure outcomes and dynamics of LRP's. However, the interaction contributed to prevent farmers from calculating unrealistic WTA's and WTP's. Our results suggest that it may be not totally necessary to introduce additional interaction mechanisms between agents (e.g., bilateral negotiations) to reproduce well the dynamics of land rental market in the Pampas. This finding is reasonable because the Pampas market is relatively transparent and both landlords and tenants know land rental prices very accurately and, additionally, there is little variation in rental prices for farms with similar land quality. However, we acknowledge that the capability of ABM's to consider direct interactions between agents may be helpful to capture macro-scale patterns in less transparent and more heterogeneous markets (Kellermann et al., 2008).

Finally, LARMA reproduced LRP's remarkably well using the assumption that prices result from equilibrium between supply and demand. This example shows that traditional economic concepts may be helpful for simplifying the simulation of relatively complex markets while maintaining suitable validity.

[7] Note that in the Pampas most farmers are market-oriented and have very similar goals.

7. Conclusions

This paper shows how to simulate large agricultural land rental markets using agent-based computational economics but still relying partially on traditional economic concepts. As an example, this paper uses LARMA, a land rental model with endogenous formation of LRP in the context of the Pampas agent-based model. LARMA considers adaptive, heterogeneous, and interacting agents but relies on equilibrium-based concepts for price formation. We conclude that agent-based modeling and traditional economic concepts may be successfully combined to capture emergent land tenure and market patterns while simplifying the model design and development. For those focused on traditional economic models, note that agent-based modeling may be an indispensable tool for simulating dynamic markets. For those developing agent-based models, note that processes such as price formation can be sometimes simplified by using well-known concepts from traditional economics. Finally, we stress that the potential ways in which agent-based and traditional economic models can be combined depends strongly on the characteristics of the market under study.

Acknowledgments

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.envsoft.2015.05.005.

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