THE PAMPAS MODEL: AN AGENT BASED MODEL OF AGRICULTURAL SYSTEMS OF THE ARGENTINE PAMPAS

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This document describes the Pampas Model following closely the ODD (Overview, Design Concepts and Details) protocol. **This is a working document that may is subject to updated and changes.**

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Summary

The Pampas Model is an Agent-Based Model intended to explore the dynamics of structural and land use changes in agricultural systems of the Argentine Pampas in response to climatic, technological economic, and political drivers.

Abstract

The Argentine Pampas, one of the main agricultural areas in the world, recently has undergone significant changes in land use and tenure and structural characteristics of agricultural production systems. Concerns about the environmental and societal impacts of the changes motivated development of an agent-based model (ABM) to explore recently observed patterns and plausible future evolution. The PM includes three main types of entities: the *environment*, the *farm* and the *farmer*. The model environment represents the northern part of Buenos Aires Province − the most productive sub-region of the Pampas that encompasses about 1,000,000 ha and has a long agricultural history. The environment contains farms of variable size defined during initialization. All farms are assumed to have the same soil and experience the same climate (represented by weather records from Pergamino, a location in the center of the region). The model involves one main type of agent: farmers who grow soybean, maize or a wheat and short-cycle soybean double crop (the most important agricultural activities in the area) on owned and/or leased farms. Each agent may have different land allocation strategies and financial (e.g., working capital) characteristics. One model time step represents a cropping cycle. On each cycle, the farmers make two main decisions: (a) decide how much area they will operate on the upcoming cycle and (b) allocates her land among a realistic choice set of agricultural activities. Farmers also adapt dynamically their aspirations based on the expected status of context factors (at the beginning of the cycle), their achieved outcomes and peers' performance. A special type of agent is the "Manager" that performs calculations that need to be available to all agents.

1 Motivation for the Pampas Model development

The region of central-eastern Argentina known as the Pampas is one of the main cereal and oilseed producing areas in the world (Calviño and Monzón, 2009). Climate fluctuations, technological innovations, and institutional and economic contexts have shaped agricultural production in the Pampas. This region has shown significant trends in precipitation during the second half of the 20th century (Berbery et al., 2006). A marked increase in late spring and summer rainfall (Minetti et al., 2003) displaced westward the transition to semi-arid regions that marks the boundary of rainfed agriculture (Berbery et al., 2006; Magrín et al., 2005). Technological innovations such as the wheat/soybean double crop (that allowed two harvests in one cycle), no-tillage planting, and genetically-modified (GM) crops have played a large role in the expansion, intensification and specialization of agricultural systems (CASAFE, 2009; Qaim and Traxler, 2005). Institutional factors such as the creation of governmental and stakeholder institutions for agricultural research and extension enhanced dissemination of technologies and fostered growth of agricultural output (Barsky and Gelman, 2009). Economic drivers also favored agricultural expansion: political and economic reforms in the early 1990s unleashed Argentina's natural comparative advantages in the production of field crops (Eakin and Wehbe, 2009; Schnepf et al., 2001). Demand for animal protein in fast-growing economies-in-transition created a large market for Argentine grains, and demand for biofuels is an increasingly strong driver (Lamers et al., 2008).

The intertwined effects of climatic, technological, institutional, and economic drivers induced significant changes in land use patterns and the distribution of production and tenure (i.e., structural characteristics) of agricultural production systems of the Pampas (Baldi and Paruelo, 2008; Viglizzo et al., 1997). Agriculture has expanded considerably, displacing other crops, pastures, and native grasslands (Magrín et al., 2005; Pengue, 2005; Viglizzo et al., 2011). The most remarkable change in land use has been the dominance of soybean: introduced in the early 1970s, soybean area (production) reached 5.1 Mha (11 Mtons) in 1990 and exploded to 18.0 Mha (40 Mtons) in 2006. The 1996 introduction of GM herbicide-tolerant soybean played an exceedingly important role in the soybean expansion, due to clear cost reductions from better weed control and lower energy costs, and much simplified agronomic management (Qaim and Traxler, 2005; Trigo and Cap, 2003).

A second observed pattern is the increase in the average area operated by farmers, accompanied by a decrease in the number of smaller farms (Gallacher, 2009). As in most market-oriented agricultural production systems (Miljkovic, 2005; Wolf and Sumner, 2001), there is a trend for the number of farms to decrease progressively, often to the benefit of a relatively higher number of larger farms. According to Argentine agricultural censuses, the average area of a production unit increased from 375 ha to 776 ha between 1988 and 2002; the proportion of total area corresponding to smaller production units (< 200 ha) decreased from 8.6% to 1.6% over the same period (Reboratti, 2005).

A third historical pattern is the rapid change in land tenure (i.e., the land ownership regime) in the last few decades. Currently, about half of the area cropped in the Pampas is not owned by farmers cultivating it (Piñeiro and Villarreal, 2005). A number of studies suggest that rented land is managed differently from owned land (Carolan, 2005; Soule et al., 2000). Our examination of farmers' records in the Pampas confirms that land owners often follow a rotation of crops that is ecologically beneficial; tenants, on the other hand, tend to maximize short-term profits. The differences in goals between land owners and tenants suggest that land tenure regime may induce quite dissimilar land use patterns.

Despite its economic importance, the agricultural sector of Argentina historically has received very little government support. A national agricultural policy – understood as long-term planning at regional or national level – has been almost inexistent (Deybe and Flichman, 1991; Schnepf et al., 2001). As a result, the evolution of land use and agricultural production in the Pampas has been mainly the result of individual decisions influenced by relative profits across competing activities, rotational considerations, and other contextual factors (Eakin and Wehbe, 2009). While agricultural decisions typically are made by individuals at a farm scale, larger-scale (regional, national) complex land use patterns often emerge that cannot be predicted from the simple summation of individual behaviors (Beratan, 2007).

Although Argentina is enjoying the economic benefits of increased agricultural production, worries are growing about long-term environmental and societal impacts: the sustainability of production, life support systems and farmers' livelihood is receiving increased attention (Altieri and Pengue, 2006; Binimelis et al., 2009; Kessler et al., 2007; Manuel-Navarrete et al., 2009; Pengue, 2005; Viglizzo et al., 2011). Such concerns motivate our development of an agent-based model (ABM) of agricultural production in the Pampas to gain insight on processes underlying recent observed changes.

2 Modeling approach

We adopt agent-based modeling as a suitable approach to quantitatively model agricultural systems, their structural change, and endogenous adjustment to policy interventions (Happe et al., 2004). Agent-based modeling is a powerful technique for simulating the actions and interactions of autonomous individuals to assess emerging system level patterns (Gilbert, 2008; North and Macal, 2007). An ABM consists of a collection of autonomous and heterogeneous decision-making entities (agents) interacting with one another and an environment. Agents have information about attributes or state of other agents and the environment, and have access to past and current values of their own state variables (e.g., economic outcomes). Agents make decisions using both prescribed rules and analytical functions; decisions are based on the information agents have available (Gilbert, 2008). An ABM also includes rules that define the relationship between agents and their environment, and rules that determine scheduling of actions in the model (Parker et al., 2003).

Agent-based models (ABMs) have been applied to a variety of problems in recent years (Heath et al., 2009; Heckbert et al., 2010). There is a vast literature on ABMs and land use changes; see reviews by Parker et al. (2003) and Matthews et al. (2007). Agricultural applications are described in Berger (2001), Berger et al. (2006), Happe et al. (2008; 2009), Nolan et al. (2009), Freeman et al. (2009) and Schreinemachers and Berger (2011b). In the region for study, the only previous use of ABMs is, to our knowledge, the simulation of changes in rangeland use in Uruguay by (Morales Grosskopf et al., 2010). Our model has many similarities with other agricultural land use models such as FEARLUS (Polhill et al., 2010), AgriPoliS (Happe et al., 2004), MP-MAS (Schreinemachers and Berger, 2011a, b) and a model of the Canadian Prairies by Freeman et al. (2009). FEARLUS and AgriPoliS are the two models most similar to ours and, indeed, our main source of inspiration for many of the processes we included. Bert et al. (2011) summarizes and compares the main characteristics of these two models and our model of agricultural production in the Pampas.

3 The Simulation Model

This document describe the Pampas Model. The description follows closely the ODD (Overview, Design Concepts and Details) protocol originally proposed by Grimm et al. (2006) and subsequently reviewed and updated by Grimm et al. (2010). Examples of ODD protocol use can be found in Polhill et al. (2008) and Schreinemachers and Berger (2011b). The organization of the sections of this paper follows the elements of the ODD protocol. However, we acknowledge that alternative approaches have been proposed for representing land use models, for example, ontology-based descriptions (Beck et al., 2010; Janssen et al., 2009). An alternative model description following the main classes of the Conceptual Design Pattern (also known as the "Mr. Potatohead" approach) proposed by (Parker et al., 2008) can be find in Bert et al. (2011).

3.1 Overview

3.1.1 Purpose of the Model

Our model is intended to explore and understand evolving structural changes and land use patterns in agricultural systems of the Argentine Pampas. Special emphasis is placed on three structural patterns observed in recent decades: (a) an increase in the area operated by individual farmers[1], accompanied by a decrease in the number of active farmers, (b) an increase in the amount of land operated by tenants and, (c) changes in land use patterns, in particular, the increasing dominance of soybean.

3.1.2 Entities, State Variables and Scales

The model consists of three main entities: the environment, the farm and the farmer. Table 1-3 presents a list of the main state variables for each entity. The current model environment aims to represent the northern part of Buenos Aires Province, the most productive sub-region of the Pampas that has a long agricultural history (Calviño and Monzón, 2009); this region encompasses about 10,000 km^2 (1,000,000 ha). The model environment is a stylized 2-D grid including a number of farms defined at initialization. Each grid cell represents a farm of variable size, also defined during initialization. The main state variables of the farms include size, soil type, owner, operator, land allocation and operator's aspiration level (specific for a farmer-farm combination). All modeled farms have the same soil and experience the same climate in the version of the model presented here. Although the current environment does not represent real geography, the model is spatially explicit because there is a topological relation among farms (a Moore neighborhood is considered).

The model involves one main type of agent: farmer households or family businesses (i.e., no corporate farms, which have different decision-making procedures) that operate owned and/or leased farms. As such, we do not model the life cycle of specific individuals who enter farming, get old and retire. Instead we assume that farming exit is only due to lack of capital. The main state variables of the farmers include operated farms, operational status and working capital. As in other land use models – such as the FEARLUS, AgriPoliS, MP-MAS and the Canadian Prairies model – agents may have different land allocation strategies and financial characteristics. A special agent type is a "Manager" that performs calculations that need to be available to all agents. A more detailed description of the state variables that characterize each entity is provided in the "Supplementary Data" accompanying this manuscript and available online.

[1] We do not refer here to "larger" or "smaller" farms, as farm sizes are fixed and set at the beginning of a model run; what changes is the total amount of land operated by an individual – that may include one or more separate farms.

Table 1. List and brief description of the main state variables for the entity *environment*.

State Variable	Description
Number of farms	Number of farms to simulate for the regions considered.
Activities and Managements	The set of production activities and agronomical managements for each activity that farmers may use in their farms.
Climate Conditions	Identifies a particular year in the historical weather record used for simulating physical outcomes (e.g., crop yields).
Physical Yields	Physical yield of each activity/management in a given soil type at time t.
Output Prices	The unit price of an output or product associated with an activity at time t.
Input Prices	Cost of inputs associated with an activity/management at time t.
Rental Price	Rental price of a given soil type at time t.
Expected States of External Context Factors	Describes the state expected at a beginning of a cycle for each contextual factor considered: (a) climate conditions, (b) output prices, (c) Input costs, and (d) institutional. They can have three possible values: (a) favorable, (b) normal and, (c) unfavorable.
Actual States of External Context Factors	Describes the states experienced during a production cycle for each contextual factor. They can have three possible values: (a) favorable, (b) normal and, (c) unfavorable.

Table 2. List and brief description of the main state variables for the entity *farm*.

State Variable	Description
Farm size	Area of the farm (in hectares).
Farm location	X and Y coordinates of the farm within the model space.
Soil type	Soil type present in the farm (only one soil type per farm).
Owner ID	ID of agent who owns the farm.
Operator ID	ID of agent who operates the farm at time t.
Land allocation	Proportion of Activities / Managements in the farm at time t.
Tenure Regime	Farm operated by its owner or by a tenant at time t.
Global Gross Margin	Aggregated gross margin for all activities within a farm (gross income minus direct costs) at time t.
Indirect Costs	Costs that apply to the entire farm, not associated with a particular activity or management at time t.
Aspiration Level	The gross margin that a farmer hopes to achieve from a given farm at time t. Although it may seem more intuitive to define this variable for a given farmer, note that a farmer could operate more than one farm in different regions and with different soil types and therefore with different expected profits. For this reason, the aspiration level is calculated for a farm/farmer combination.

Table 3. List and brief description of the main state variables for the entity *farmer*.

State Variable	Description
Operated Farms	List of all farms operated by the farmer (as owner or as tenant) at time t.
Total Operated Area	Summed area of all farms operated by the farmer (as owner or as tenant) at time t.
Operational Status	Status of farmer. At time t, It can take one of seven possible values: (a) Owners-only: owners operating only their own farm, (b) Owners-tenant: owners operating their farms and one or more rented farms, (c) Tenants-only: farmers who do not own land but operate rented land, (d) Landlords: owners renting out their farm, (e) Bankrupt: tenants-only who cannot lease any farm because of insufficient working capital, (f) Out of business: tenants-only excluded because owner returned to active farming and, (g) Inactive: farmers held in reserve for future use.
Working Capital	Amount of money accumulated by the farmer at time t.
Social Network	List of farmers with whom the farmer has social contact. Currently the list includes farmers who operate farms in Moore physical neighborhood.

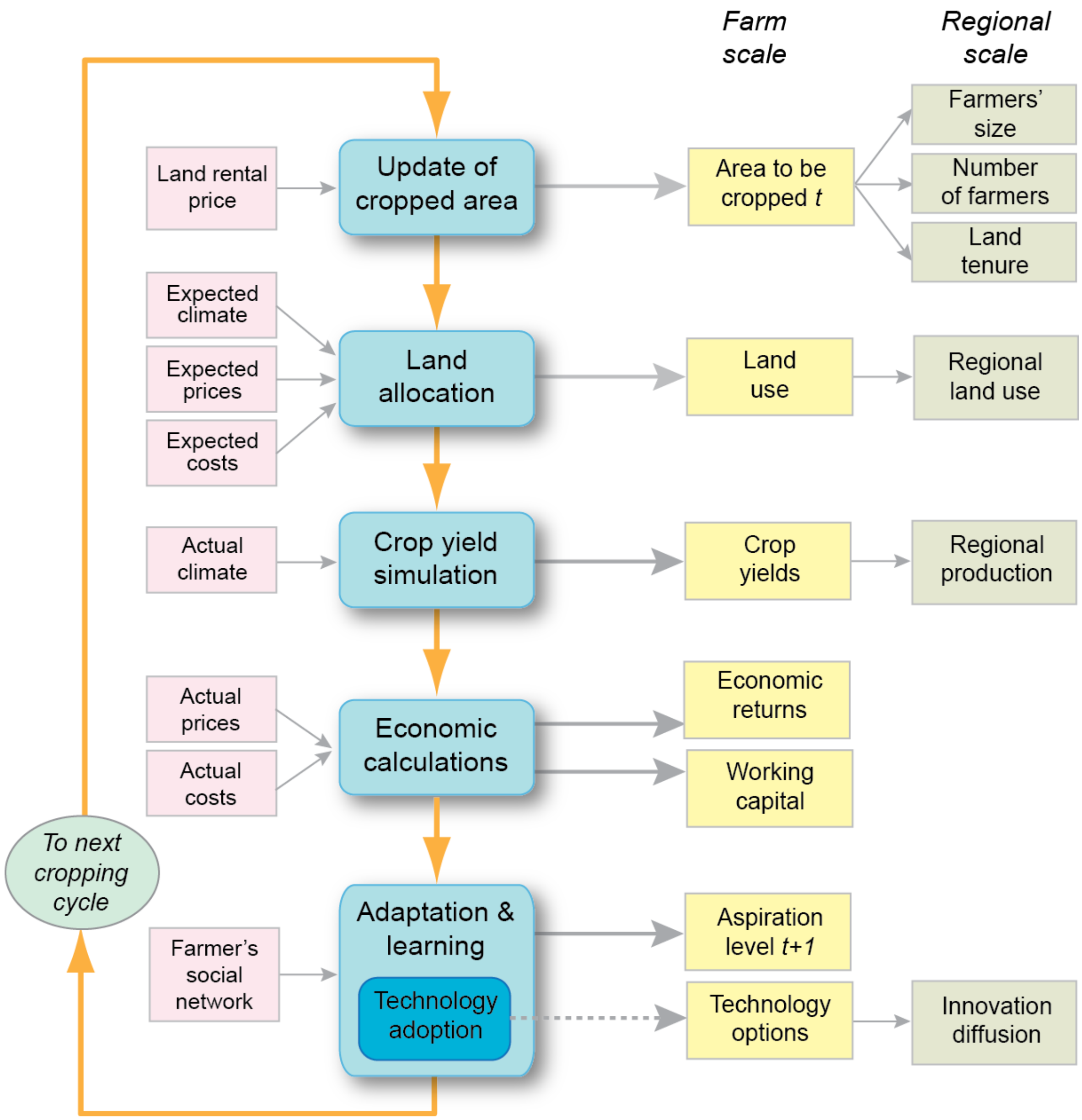
3.1.3 Process Overview and Scheduling

One model time step represents a cropping cycle (from April to March of the next calendar year). In the simulations presented here, the model loops through 100 simulated cropping cycles (labeled with numbers starting at 1900) after performing all initialization steps. Figure 1 shows the order in which model processes take place within a cropping cycle and for a single farmer; details about each process are given in Section 2.3.

At the beginning of each production cycle a farmer adjusts her economic aspirations for the current cycle based on the *expected* status of context factors (climate conditions, output prices, input costs). Then, the farmer decides whether she can (a) farm additional land, (b) maintain the same area as in the previous cycle or, instead, (c) must release some or all of the previously farmed area. Currently, the only way to expand cropped area is by renting in additional land (i.e., the model does not include land sales). Subsequently, farmers allocate their land among a realistic choice set of Activity/Managements (AMs), defined by the combination of (a) an Activity (maize, full-cycle soybean and wheat-soybean) and (b) agronomic Management. After land is allocated, the physical outcome (yield) of each selected AM is retrieved from lookup tables built using biophysical crop models and experienced climate conditions. From simulated yields and experienced crop prices and input costs (specified as model inputs), economic returns are calculated: the end result is an updated value of a farmer's Working Capital (WC) at the end of the production cycle. Achieved economic returns are then assessed in relation to the farmer's initial aspiration and peers' performance. This assessment drives an adaptation of the farmer's Aspiration Level – AL, a special value that separates outcomes perceived as successes or failures

(Diecidue and van de Ven, 2008) – that may be used as input to decisions in the following cropping cycle. This schedule, at high level, is broadly similar in terms of events and events ordering to that of FEARLUS model (Polhill et al., 2008).

Figure 1. Conceptual diagram of the sequence of processes for a single farmer in a production cycle. External context drivers are listed on the left of the diagram, and state variables associated with each process are shown on the right. Farm-level state variables can be subsequently aggregated into regional-level variables (e.g., farm-level crop yields can be aggregated into regional production of each crop).



3.1.4 Software Environment

Multiple software frameworks exist that reduce significantly the programming effort and time required to develop ABMs and the chances of making errors (Nikolai and Madey, 2009; Railsback et al., 2006). Our model is implemented in REPAST, the REcursive Porous Agent Simulation Toolkit (repast.sourceforge.net), a free, Java-based, open-source toolkit (North et al., 2006).

3.2 Model Design Concepts

Emergence. Four main regional-level features emerge from individual farmer behavior and interactions among agents: (a) regional land use (area planted with each crop), (b) regional production of major crops, (c) regional farm structure (frequency distribution of areas operated by active farmers), and (d) regional land tenure (the areas operated by owners and tenants).

Adaptation. In each cropping cycle, farmers may use three adaptation mechanisms: (a) increasing or reducing the area farmed, depending on available working capital (WC), (b) choosing a different land allocation if they are unsatisfied with previous outcomes, and (c) adjusting their AL; details on aspiration adjustments are provided in the "Sub-models" section.

Objectives. Farmers aim to maintain or increase their WC, and to maintain or expand cropped area. If a farmer's WC drops below the minimum required for production, she must reduce the area cropped or even exit farming. During the land allocation process, farmers seek to achieve economic outcomes above their AL, otherwise they will be unsatisfied and will search for a different allocation.

Learning. No learning is included in the model version described here.

Prediction. Farmers who decide to switch land allocation – because of dissatisfaction with achieved results – implicitly assume that their most recent allocation also is likely to be unsatisfactory during the following cropping cycle. Farmers also may have expectations about the status of context factors in the upcoming cycle based on external information (e.g., seasonal climate forecasts, commodity price projections or futures markets).

Sensing. Farmers are aware of their current WC and consider this variable in decisions about renting land in or out. Farmers have access to past and current land allocations and farm-wide gross margins (FGMs) for all farms over which they make production decisions. Farmers are assumed to know the economic outcomes achieved by their peers (in this case, their eight Moore neighbors) during a cropping cycle. Finally, farmers are aware of the expected and experienced status of external context factors and of current land rental prices.

Interaction. Farmers may imitate the land use of neighbors (see Section 2.3.1.2). Landlords and tenants interact indirectly through the land rental process; the interaction is mediated by the Manager, who matches the supply and demand of rental land.

Stochasticity. Stochasticity is present in multiple model components. During initialization (i) farm sizes are generated stochastically (in some scenarios) so that size distribution is consistent with agricultural census data; (ii) farmers are randomly assigned to each farm (but respecting observed proportions of owner- and tenant-operated farms); and (iii) AMs are stochastically assigned to each farm plot. Once the model starts iterating, a stochastic mechanism decides if landlords with sufficient WC return to active farming. The order in which potential tenants choose rental farms is stochastic. Finally, land use selection mechanisms involve either random selection or imitation (in which the peer to be imitated is selected randomly).

Collectives. There are no aggregations of individuals or intermediate levels of organization in the current version of the model.

Observation. Multiple low-level and aggregated variables are collected after each production cycle and written to output files at the end of a simulation. The output variables are organized into four text files containing separate results for farm plots, farms, farmers, and the Manager.

4 Model Details

In this section we provide brief descriptions of (a) the main sub-models and mechanisms involved in the model, (b) the initialization process and, (c) the main input variables.

4.1 Main Sub-models

4.1.1 Cropped Area Update (CAU)

This sub-model defines the area to be farmed by an agent on a production cycle. The only way to expand production is by renting in additional land; the current model does not include land sales (a reasonable approximation, as farm sales volume in the Pampas is very low). Thus, the Pampas model include a LAnd Rental MArket model (LARMA) with endogenous formation of land rental price. LARMA is embedded in CAU sub-model. This section describes de CAU sub-model and the LARMA model.

4.1.1.1 Approaches to modeling land rental markets

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

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

LARMA is 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 some 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 partially adjust their economic aspirations based on 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' conditions (e.g., working capital; WC) and personal characteristics (e.g., risk aversion).

Of course, land markets as heterogeneous and spatially organized markets are far from the ideal assumption of perfect competition where homogenous goods are traded with equal access, free entry and perfect and complete information (Kellermann et al., 2008). Nevertheless, characteristics of the land market in the Pampas allow us to partially 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. In fact, farmers may anticipate quite accurately LRP when they plan moving to areas where they have not farmed before. 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 (more than half of the area is transacted every year); 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 in the Pampas) and they aim to achieve as much profitability as possible.

Finally, other agricultural land use ABMs include land market sub-models. This is the case, for instance, of AgriPoliS and FEARLUS (this only considers land sales) two models with a similar purpose to our Pampas ABM. The approach behind the land market sub-models of AgriPoliS and FEARLUS differs from the one used in our Pampas ABM: while our land market model relies partially on concepts from neoclassical economics, AgriPoliS and FEARLUS are based on different auction mechanisms (e.g., first-price or Vickery). This implies individual interactions among agents not present in our model. Beyond this main difference, there are other differences and similarities among the models that will be specified in the following sessions.

4.1.1.2 Details of CAU and LARMA

The CAU sub-model of the Pampas ABM 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. Figure 1 shows an overview of the stages involved in the CAU sub-model.

4.1.1.2.1 Definition of potential farmland supply and demand and formation of Land Rental Price

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). As mentioned above, the model assumes all farms (of a given soil quality) will be rented at the formed LRP during a cropping cycle. Formation of LRP by the LARMA component involves three consecutive steps: (a) the identification of potential supply and demand; (b) the formation of “Willing to Accept Price” (WTAP) and “Willing to Pay Price” (WTPP); and (c) the calculation of a Market Clearance Price (MCP) representing the LRP for the current cropping cycle. Each step is described below.

The *first step* involves the definition of potential[2] supply and demand to identify those agents who need to form WTAP and WTPP respectively. Farmers who have not sufficient WC or unsatisfied farmers (see below) will release previously rented land or rent out their own land. This land farms will be available for rent (potential supply). A similar assumption is made for the land market component of AgriPoliS, where part of land available for rent comes from illiquid farmers (the other source is land which is free because either the rental contract has ended, or a farm manager terminated the contract). Conversely, farmers with surplus WC will be interested in renting additional land (potential demand). Thus, at the start of a production cycle (prior to formation of LRP) the model assesses whether each individual farmer, depending on the farmer´s WC; 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

[2] Note that we refer to “potential” supply and demand because, not having been defined the LRP: (a) tenants cannot anticipate if their available WC will be sufficient to afford rental costs and, (b) some owners will define if they rent out their land depending on the formed LRP. For this reason, at this step LARMA identifies agents who could potentially rent additional land -they will need to form WTPP- and owners who could rent out their farms depending on the formed land rental price.

all previously farmed land. This assessment depends on 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 2 lists the farmers who may need to form WTAP or WTPP.

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 exit (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[3]. 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 each agent 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, this farmer will actually rent out her farm only if the formed LRP is higher than her WTAP.

[3] 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.

Figure 1. Overview of stages and main processes involved in the Cropped Area Update.

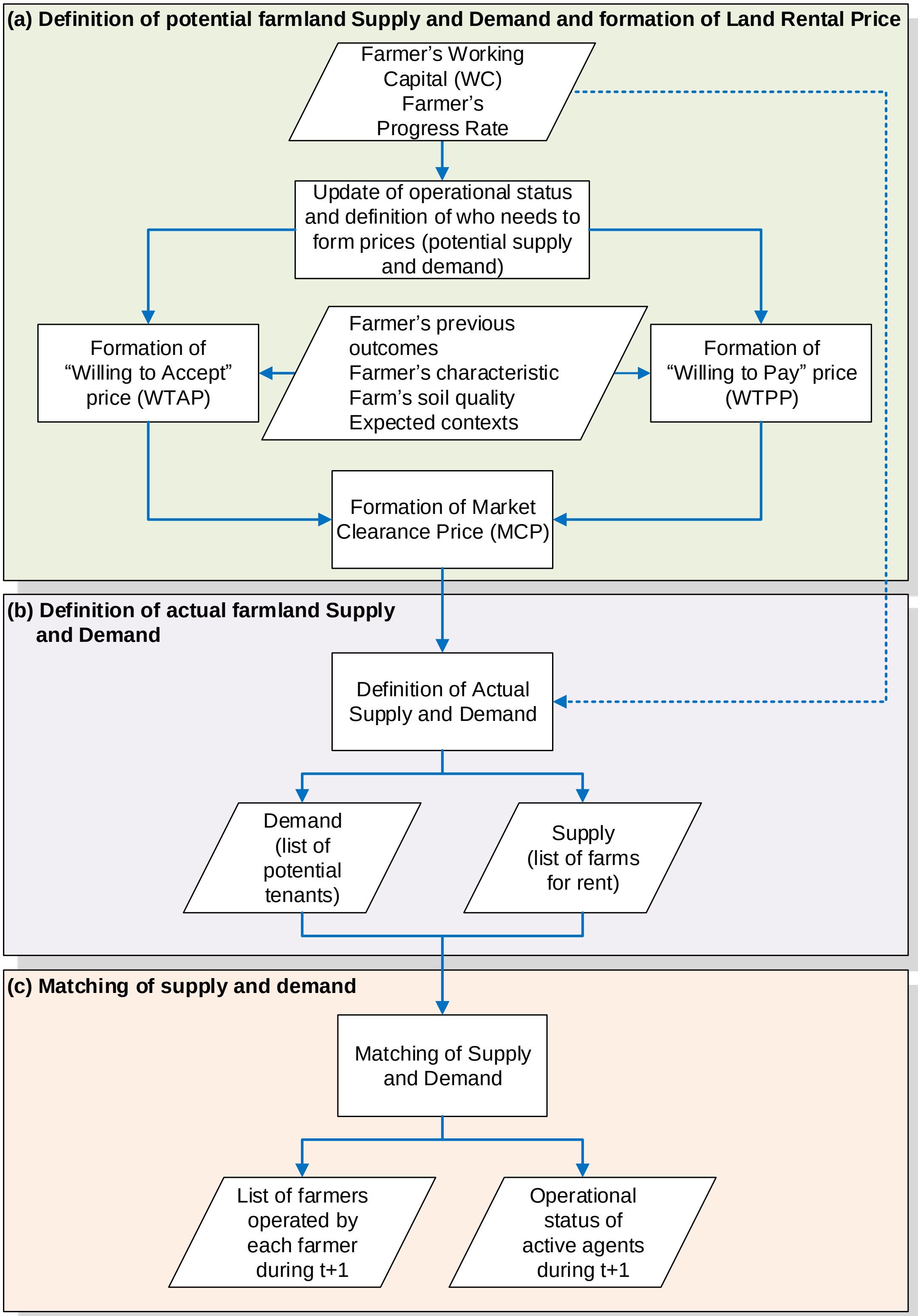


Table 3. Summary of agents who need to form WTAP and WTPP on a given cropping cycle. Agents may have different land tenure status on each cycle: (a) “owners-only” crop owned land only, (b) “owner-tenants” crop both owned and rented land, (c) “tenants-only” operate only rented land, and (d) “landlords” 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.

4.1.1.2.2 Calculation of WTA and WTP

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. Thus, three calculations are required to form WTAP: (a) the computation of Expected Utility (EU) for a set of m possible AMs in n recent cycles (m and n are model parameters). This is an estimation of the risky outcomes that the owner could achieve from operating his farm. (b) the calculation of the Certainty Equivalent (CE) of the EU, to transform risky production outcomes to “for sure” equivalent outcomes and (c) the calculation of the WTAP based on CE. The details of the calculations are provided below:

First, the EU is computed as:

$$EU = \frac{1}{n \cdot m} \cdot \sum_{i=1}^{n} \sum_{j=1}^{m} u(w_{i,j}) \qquad (1)$$

Where i represents an AM, j a cycle and u the EU function:

$$u(w) \propto \begin{cases} \ln w \\ \dfrac{w^{1-r}}{1-r} \end{cases} \quad (2)$$

The Utility function depends on two parameters: (a) r, the coefficient of constant relative risk aversion and (b) w, the owner´s wealth, computed as:

$$w_{i,j} = W_0 + WC_j + (GM_{i,j} - IC_j) \qquad (3)$$

Where, W_0 is owner´s initial wealth (this quantity was estimated as 40% of the value of the farm land4), WC_t is the current owner´s Working Capital (we assume that the farmer has, at least, sufficient WC as to operate his farm), $GM_{i,j}$ is the farm-wide Gross Margin assuming AM i on cycle j and, IC are the Indirect Costs on cycle j; Indirect costs include structural (S), management $(Mgmt)$, taxes (T) and -for tenants- land rental costs.

Second, once EU was calculated, the CE is computed as:

$$CE = u(EU)^{-1} \quad (4)$$

The CE is the "for sure" value that would make a farmer indifferent between facing risky cropping outcomes or accept the minimal-risk rental fees (Hardaker et al., 2004, p. 30). The CE is expressed in monetary terms.

Finally, the WTAP depends directly on CE: to derive WTAP from CE we first subtract W_0 and WC_t from CE in order to we get only the production-related component. Then, as the owner must pay S and T indirect costs (but not Mgmt) whether he rents out his farm (and as CE is computed using NM values), we sum S and T to CE (and subtract Mgmt) in order to compute the minimum price that the owner should ask for renting his land to get - after paying S and T- a NM comparable with the risky incomes from production. Thus, the WTAP is computed as:

$$WTAP = CE + S + T - Mgmt \qquad (5)$$

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 envision to achieve during the upcoming cycle. We also assume that the target GM is quantified by the farmer's AL adjusted by

[4] The definition is based on the assumption that a farmer will not sacrifice future income potential by selling crop land, but can borrow up to 40% of his land value.

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 (Lant and Shapira, 2008). We assume also that a farmer seeks a Minimum Return Rate (r; a model parameter) for the capital that he must lay out at the beginning of a cycle. This capital – which we refer to as "Committed Capital" (CC) – includes all fixed direct costs (i.e., seeds, fertilizers, labors, etc.) and land rental. The details of calculation of WTPP is shown below:

We assume a potential tenants seeks obtain a Net Margin (or revenue) based on the capital that he commit (CC) and a minimum return rate (r). A very similar concept is used in AgriPolis, which consider a beta parameter equivalent to our r. Thus, the calculation of how much land rental to pay (WTPP) is driven by the NM, which can be defined as (we used the s subscript for all terms that may vary according soil type):

$$NM_s = GM_s - IC_s \quad (6)$$

Where GM is Gross Margin and IC is Indirect Costs. This terms are computed as:

$$GM_s = GI_s - FDC_s \quad (7)$$

$$IC_s = LRP_s + OIC \quad (8)$$

Where GI is the Gross Income (production outcome times sale price), FDC is the Fixed Direct Costs and OIC is Other Indirect Costs (all indirect costs except Land Rental Price). Then, using equation 8, NM can be re-written as:

$$NM_s = GM_s - LRP_s - OIC \quad (9)$$

Based on this, LRP –which represents WTPP, the main unknown variable- is:

$$LRP_s = GM_s - OIC - NM_s \quad (10)$$

As we assume that $GM_s \approx AL_{EC,s}$, the equation can be re-written as:

$$LRP_s = AL_{EC,s} - OIC - NM_s \quad (11)$$

Both $AL_{EC,s}$ and OIC are available data: $AL_{EC,s}$ is endogenously computed by the Aspiration Level component of the Pampas Model and OIC is provided as model input data. Then, to calculate LRP_s, the farmer needs to assign a value to NM_s. As mentioned above, the net margin the farmer may desire to get at the end of the cycle can be defined according to the capital committed and the desired profitability rate:

$$NM_s = CC_s \cdot r \quad (12)$$

Where CC_s involves:

$$CC_s = FDC_s + LRP_s \quad (13)$$

Then replacing equation 13 in 12, NM_s can be re-written as:

$$NM_s = FDC_s \cdot r + LPR_s \cdot r \quad (14)$$

And using equation 14 in equation 11, then we can calculate the maximum Land Rental Price that the potential tenant could pay to reach the sought NM :

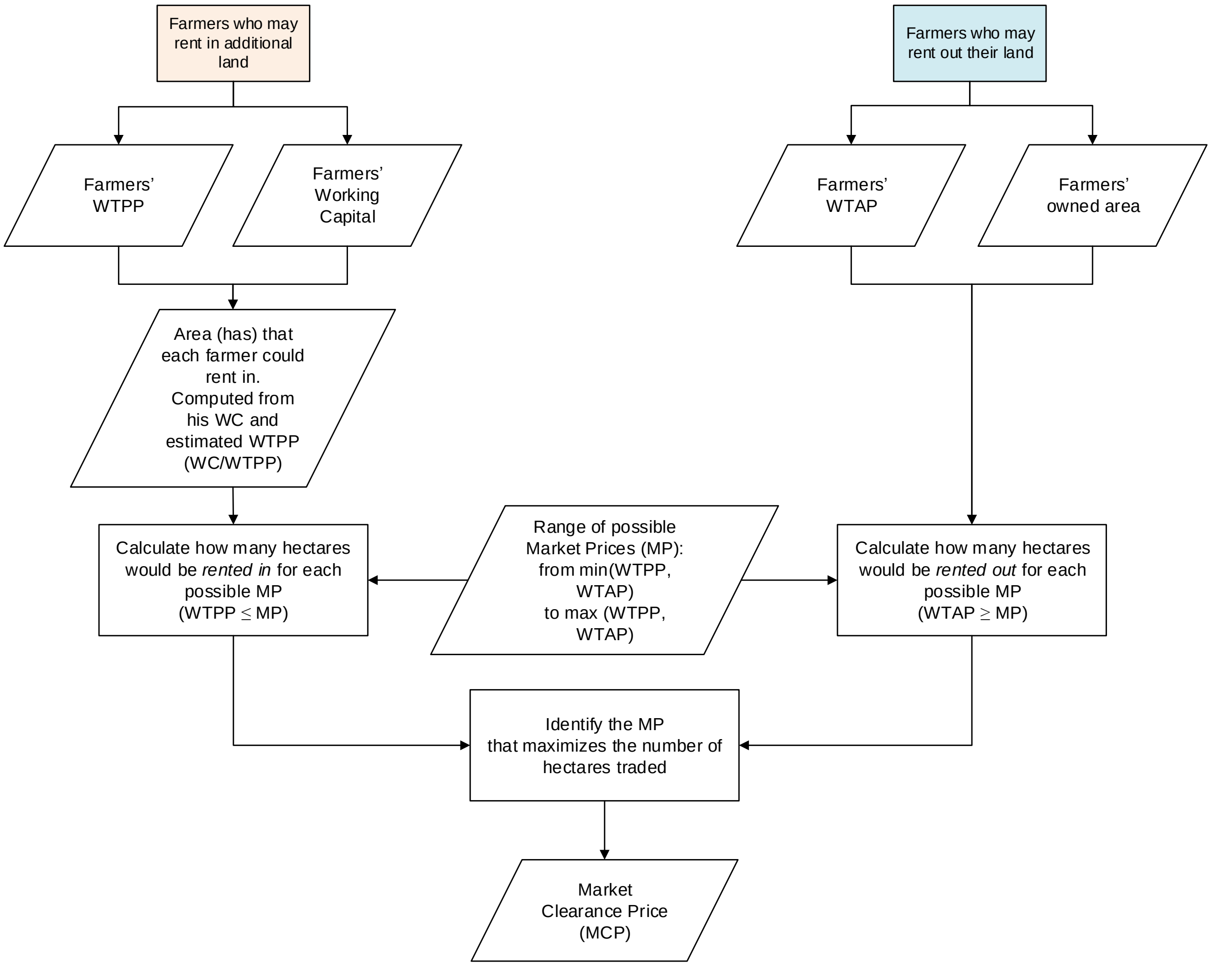
$$LRP_s = \frac{AL_{EC,s} - OIC - FDC_s \cdot r}{(1+r)} \quad (15)$$

Finally, as we mentioned, $LRP_s \equiv WTPP$.

We assume that farmer only calculate WTPP for the soil/s type/s he operated in the last cycle (if the farmer operated two farms with two different soil types, then she will calculate two WTPP). When the potential tenant assess renting a new farm with a soil type different to the soil type(s) of farm(s) rented the previous cycle, we assume that the farmer do not compute WTPP and "accept" the LRP defined by the market.

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 ≥ 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 ≥ WTAP and then adding up farm areas for those owners. The MCP, then, is solved as the intersection of the demand and supply curves. Figure 2 represents main processes of MCP formation.

Figure 2. Overview of main processes involved in the calculation of the Market Clearing Price (MCP).



4.1.1.2.3 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).

4.1.1.2.4 Matching actual farmland supply and demand

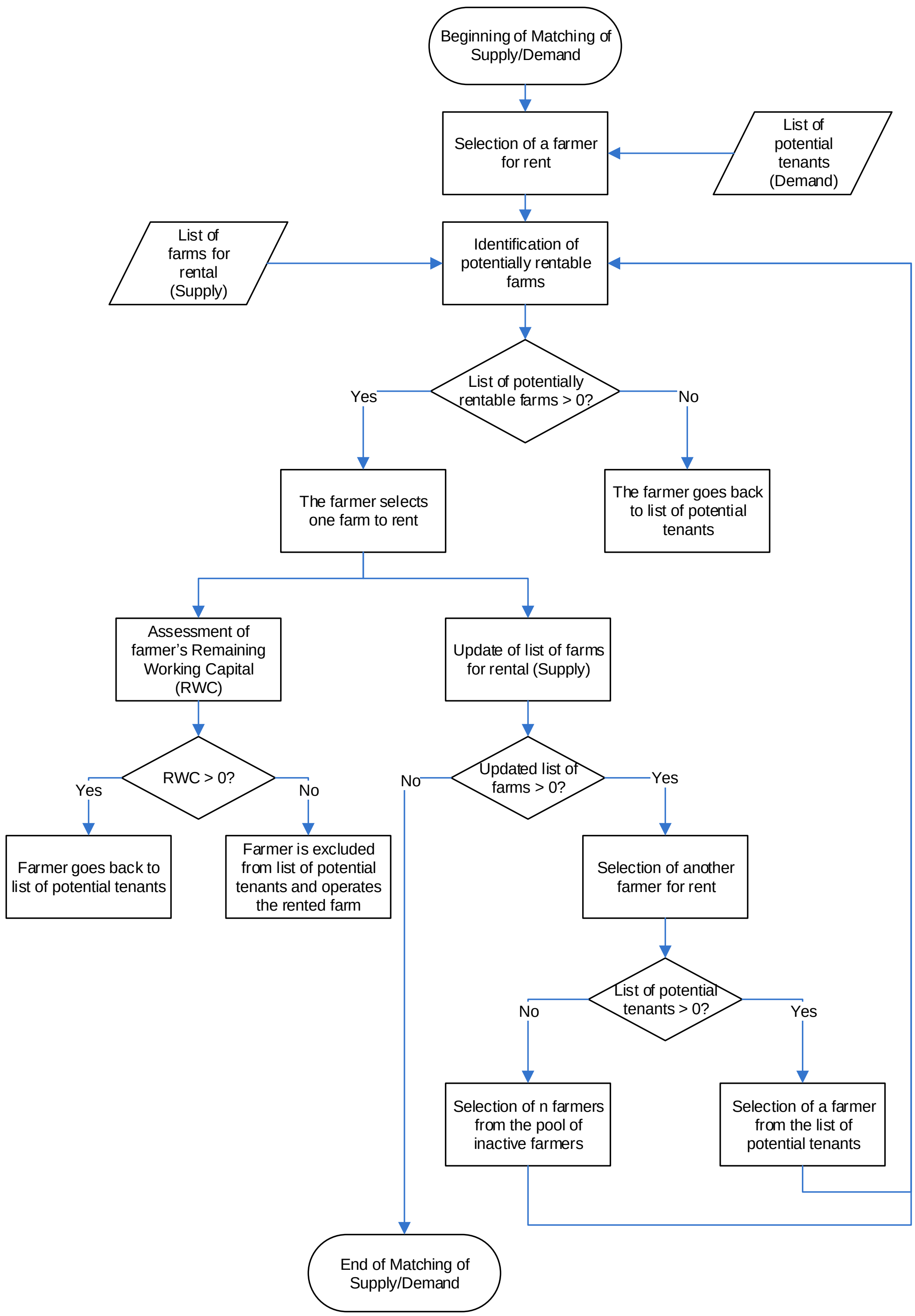
The third stage of the CAU sub-model matches actual supply and demand to finally define the area that each agent will crop. Figure 3 shows details of the matching of supply and demand. This process involves iterating over the list of potential tenants. A farmer is initially selected from the list of potential tenants[5]. 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[6] 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.

AgriPoliS uses an auction mechanism to allocate land. To allocate these set of plots, the land market is designed as a sequential auction, i.e., it is possible to bid for only one plot at a time. This means that the auctions for a single plot are repeated until all plots are allocated or there are no further positive bids. LARMA assumes that all land rental contracts have a fixed duration of 1 year. This is a reasonable assumption for the Pampas. However, we assume that a tenant has the priority to continue operating a farm: if the tenant has sufficient WC, he rents the farm (and the farm is not added to the list of farms for rent). Conversely, two types of rental contracts considered in AgriPoliS: (a). land rental contracts with a fixed duration (as in LARMA) and (b) contracts in which plots can be "renegotiated" at the end of each production period (this has some similarities with the priority assigned to tenants in LARMA).

[5] The probability of being selected is proportional to the potential tenant's WC – reflecting an advantage for wealthier farmers.

[6] The minimum area acceptable for leasing is defined as a function of the total area operated by a farmer.

Figure 3. Overview of main processes involved in the Matching of Supply and Demand.



4.1.1.3 Land Allocation

This sub-model defines land use in a farm on each production cycle: it allocates an Activity/Management (AM) to each plot. An AM is defined as the combination of a production Activity and a specific agronomic Management (AMs are termed "land uses" in FEARLUS). The model includes three agricultural Activities: (a) full-cycle soybean, (b) maize, and (c) wheat/soybean double crop. In turn, each Activity has two possible agronomic Managements, defined by unique combinations of genotypes, planting dates, densities and fertilization. That is, a total of six AMs are defined that are representative of current practices in the target region. AMs were defined with experts from the Asociación Argentina de Consorcios Regionales de Experimentación Agrícola (AACREA, www.aacrea.org.ar), the farmers' organization partnering in this project.

The first step in the land allocation module is the definition of the choice set. We assume that all farms have six equally-sized plots; therefore, the proportion of farmland allocated to each AM may take seven possible values: [0, 1/6,…, 6/6]. With six AMs and six plots per farm, there are 462 Activity/Management/Proportions (or AMPs). This number, however, is valid for farmers who do not have crop rotation restrictions. For farmers who follow a strict rotation (e.g., 1/3 of the land *must* be assigned to each Activity) the number of AMPs quickly decreases to 27.

The second step involves a search triggering process, in which farmers decide whether they will repeat the land allocation used in the previous cycle or, alternatively, search for a new one. Search triggering is supported by empirical research elsewhere (Polhill et al., 2010). The model includes two alternative search triggering mechanisms: (a) "random", and (b) "N out of M." In the random mechanism, the farmer defines randomly on every cycle if he will repeat the previous land use or will search for a new land allocation. In the " N out of M " mechanism, search is triggered if the farmer has been "unsatisfied" with N economic outcomes (consecutive or not) in the M most recent production cycles. A farmer is unsatisfied when his economic outcome is lower than his AL. N and M are defined for each agent at initialization (we used N =2 and M =3 for all simulations). Similar mechanisms are used in other models: for instance, in FEARLUS a farmer changes land use after being unsatisfied for N consecutive years.

In a third step, a farmer who has decided to change land allocation must select a new AMP using one of two mechanisms: (a) "random," in which an AMP is randomly selected from the choice set – but excluding the previous (unsatisfactory) AMP – or (b) "margin-weighted selection of a peer to be imitated", in which the farmer imitates the AMP previously used by one of his peers (here, the eight Moore neighbors of the farm for which the agent is deciding land use). Only neighbors with similar rotation preferences are considered. The agent to be imitated is selected stochastically with a probability proportional to his achieved economic profit (i.e., successful neighbors are more likely to be imitated). In simulations presented here, both land use selection mechanisms were tested (Table 2). Other models use various forms of imitation to select land use. In FEARLUS, for example, the land use selected is a combination of uses selected by neighbors (weighted according to various schemes).

Finally, once a farmer has selected a land use for the current cropping cycle, she must assign AMs to specific farm plots. There is no temporal overlap among activities, so all transitions are theoretically possible. Nevertheless, a preferred sequence has agronomic advantages: (1) full-cycle soybean, (2) followed by wheat-soybean, (3) followed by maize. Whenever possible, a farmer attempts to respect this sequence. If this proves impossible (e.g., if one of the Activities is not included in the selected AMP), the farmer tries to allocate to each plot an activity different to that used in the previous cycle. The farmer repeats the same activity in a plot only if there is no other option. No farm lot is left fallow.

4.1.2 Crop Yield Simulations

Crop simulation models in the Decision Support System for Agrotechnology Transfer (DSSAT) package (Jones et al., 2003) are used to simulate physical yields of each AM. CERES-Maize and Wheat and CROPGRO are used to simulate maize, wheat and soybean yields respectively. These models simulate yields for each farm as a function of soil type, crop genetic characteristics, and daily weather. These models have been calibrated and validated for the Pampas (Guevara et al., 1999; Mercau et al., 2007). Crop yields are pre-calculated using DSSAT models and stored in pre-defined lookup table (model input). For some scenarios we used simplified yield trajectories instead of simulated yields (e.g., near-normal and constant yields for each AM along the entire simulated window).

4.1.3 Economic Calculations

This module calculates the economic results for a farmer during one full production cycle. The result of the module is the financial balance for a farmer and his/her household at the end of a cycle. The balance is expressed as the working capital accumulated by an agent at the end of the cycle. Briefly, the accumulation of working capital is the result of the balance between available capital from previous cycles, total income received, and total expenses incurred during a production cycle. The various sources of income and types of expenses are discussed in subsequent sections, and specific details are given on the calculation of each item.

4.1.3.1 Financial balance at the end of a production cycle

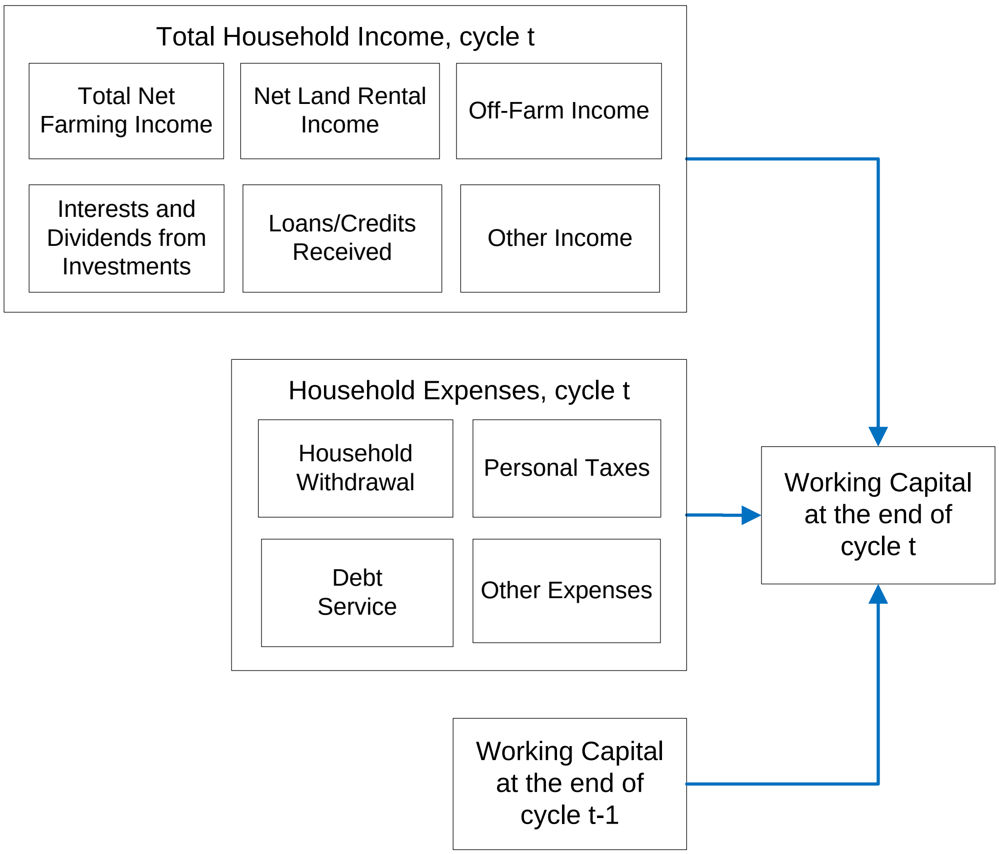
This module calculates the economic results for a farmer during one full production cycle. The result of the module is the working capital accumulated by an agent farmer or his/her household at the end of production cycle t. This quantity is calculated as:

$$WC_t = THI_t - E_t + WC_{t-1} \text{ , where}$$

- THI_t represents the total household income received by the farmer or members of his/her household during production cycle t. This income may originate from farming activities or other sources (e.g., off-farm employment).
- E_t includes all expenses incurred by the farmer and members of his household during production cycle t, including personal income taxes, household withdrawals, and debt service. Calculation of household expenses is described in Section 5.
- WC_{t-1} is the working capital available at the end of production cycle $t-1$.

A schematic description of the quantities involved in the calculation of WC_t is shown in Figure 4. Because of its importance, we start by discussing the calculation of farming income (Section 2). Other sources of income are discussed in 6.3.1.4.2. Calculation of household expenses is described in Section 6.3.1.4.4.

Figure 4. Calculation of working capital accumulated by a farmer/household at the end of production cycle t.



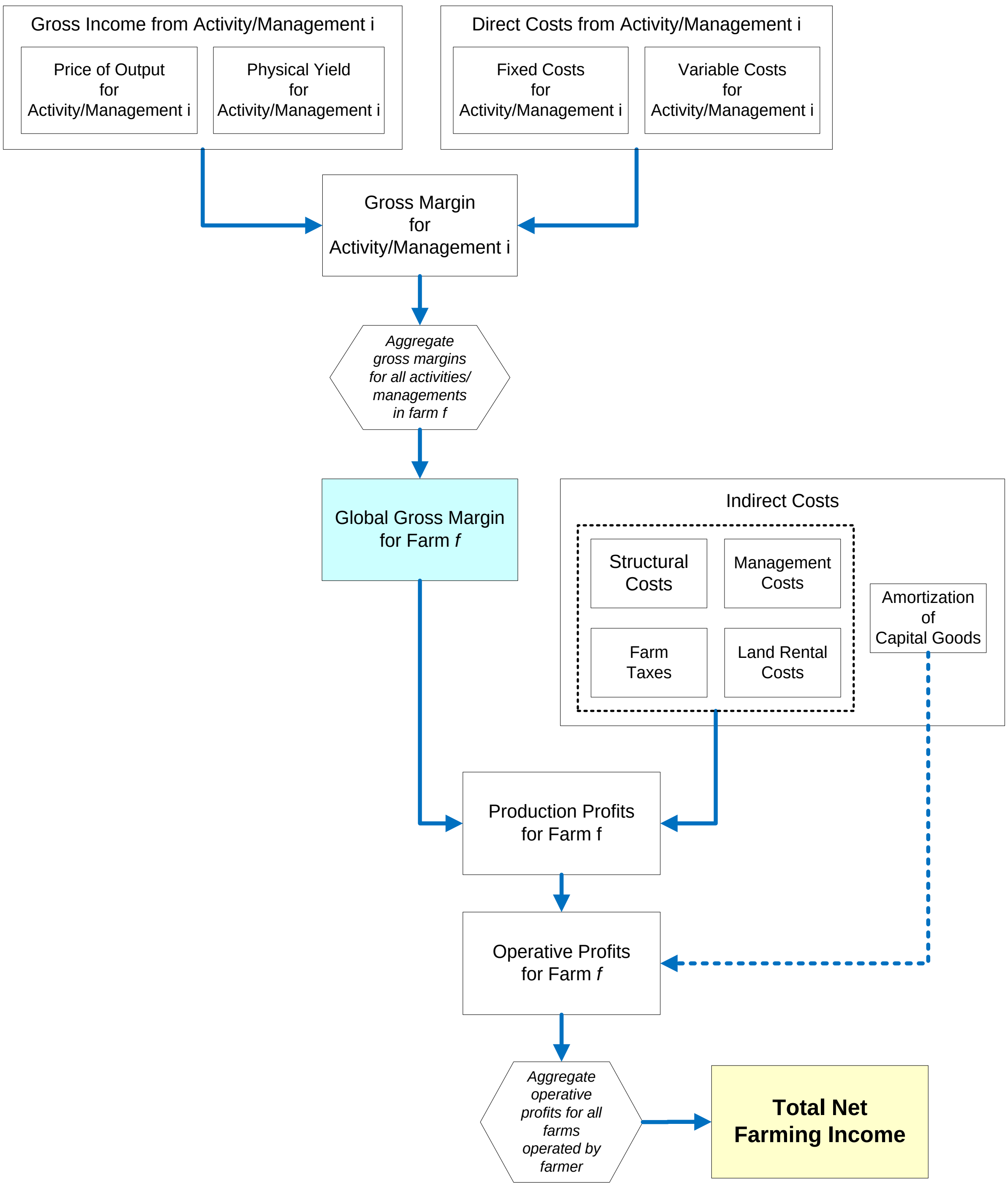
4.1.3.2 Calculation of total net farming income

This section describes the calculation of total net income from all farming activities in all farms operated by an agent during production cycle t. Income is denoted as "total" because it involves (i) all farming activities (e.g., agriculture, beef or dairy production, etc.) carried out by a farmer agent and (ii) all farms (owned and/or rented) operated by an agent during production cycle t. This quantity also is denoted as "net" because production costs have been deducted during calculation. A schematic description of the calculation of total net farming income is displayed in Figure 5. At present the model considers only agricultural production; for this reason, the diagram includes only items associated with calculation of profits from agriculture.

To organize this description, we have followed the guidelines proposed by the Asociación Argentina de Consorcios Regionales de Experimentación Agrícola (AACREA). Extensive details on the calculation of farming income can be found in AACREA's technical publication "Normas para calcular los resultados económicos económicos de las empresas" by F. Colombo, J.M. Olivero Vila, and T. Zorraquín. Copies of this publication can be requested from AACREA (www.aacrea.org.ar). Adoption of the AACREA terminology also facilitates discussions and presentation of results to stakeholders.

The farm-wide gross income includes income generated by all farming activities carried out in farm f during production cycle t. First, the gross income of an activity/management is calculated for each plot in a farm (Section 2.1) and aggregated over all plots allocated to that activity/management. Second, direct costs are calculated for the activity/management in a plot and also are aggregated over all plots allocated to that activity/management (Section 2.2). Third, the difference between gross income and direct costs yields the gross margin for a given activity/management in a farm. The global or farm-wide gross margin is computed by aggregating the gross margins of each activity/management (Section 2.3). Fourth, indirect costs that apply to the farm as a whole are calculated (Section 2.4). Fifth, indirect costs are subtracted from the global gross margin: this calculation yields the "operative profits" or "production profits" for a farm (depending, respectively, on whether amortization of capital goods is included or not; Section 2.5). Finally, operative/production profits are aggregated for all farms operated by a farmer during production cycle t (Section 2.6). The end result is the global net farming income for a farmer.

Figure 5. *Calculation of global net farming income. The model currently includes only agricultural production activities, therefore only items associated with agriculture are included.*



4.1.3.2.1 Gross income from an agricultural activity/management

The gross income of an activity/management is calculated for. A given activity/management is assigned by the farmer to each plot p in a farm during the land allocation process (see module on land allocation). The term "activity" indicates a major type of production activity, for example, "maize production" or "dairy production." The model currently includes three agricultural activities: (i) full-cycle soybean, (ii) maize, and (iii) a wheat/soybean double crop (wheat followed by short-cycle soybean). The term "management" describes the specific way in which an activity is carried out. For instance, there can be two or three different agronomic managements of a maize crop, each involving a unique combination of management decisions such as planting date, genotype used, fertilization amount, etc.

The gross income of activity/management i during production cycle t is calculated as:

$$GI_{i,t} = Y_{i,t} \cdot P_{i,t}^{OUT} \cdot A_{i,t} \quad , \qquad (1)$$

where $Y_{i,t}$ is the physical yield (expressed in physical units of product per unit area, e.g., tons of soybean or kg of beef per hectare) of activity/management i in production cycle t, $P_{i,t}^{OUT}$ is the unit price of the output or product (e.g., dollars per ton of soybeans) associated with that activity/management in production cycle t, and $A_{i,t}$ is the area of all farm plots occupied by activity/management i during cycle t.

The physical yield $Y_{i,t}$ achieved by any activity/management involving agriculture is pre-calculated outside the model using biophysical crop simulation models. Yields are simulated for each activity/management using as input daily weather (observed or synthetic) for all cropping cycles. Details on the yield calculations are given on a separate chapter. Yields simulated for all activity/managements and cropping cycles are specified in the model initialization data base. The price of each output in production cycle t ($P_{i,t}^{OUT}$) also is specified in the initialization data base.

4.1.3.2.2 Direct costs for an agricultural activity/management

Direct costs include expenses associated with a specific agricultural activity/management. In turn, direct costs can be divided into (i) fixed costs and (ii) variable costs. Fixed costs do not depend on the physical yield of the activity/management, whereas variable costs are calculated as a function of yield.

4.1.3.2.2.1 Fixed direct costs

Fixed direct costs are those costs or expenses associated with a particular agricultural activity/management (AM) which are *independent* of yields for that AM. The total fixed direct costs for activity/management i during production cycle t are calculated as

$$FDC_{i,t} = \left(FDC_{i,t}^{FL} + FDC_{i,t}^{S} + FDC_{i,t}^{AC} + FDC_{i,t}^{O} \right) \cdot A_{i,t} \cdot ESF_{FDC} \quad , \qquad (2)$$

where the four terms between parentheses in the right side of the equation correspond to the direct costs per hectare respectively associated with:

- Field labors (excluding harvest);

- Seed;
- Agrochemicals; and
- Other costs.

Each activity/management has an associated set of inputs (e.g., number and types of field labors, type and quantity of seeds, etc.) that are specified in the initialization data base. Costs for these inputs are calculated per unit of area, so the fixed direct costs per ha are multiplied by $A_{i,t}$, the area of all farm plots occupied by activity/management i during cycle t. Finally, all values are multiplied by a factor that reflects economies of scale in fixed direct costs (ESF_{FDC} ; see Section 2.2.1.5). The following sections provide details on the calculation of each component of the fixed direct production costs.

4.1.3.2.2.1.1 Field labor costs

This item includes the cost of all field labors (e.g., planting, spraying herbicide) required by an agricultural activity/management i. Harvesting costs are *not* included in this item, as they are considered to be part of direct variable costs (because they are a function of crop yield).

The types and number of field labors required by each activity/management are specified in the model initialization data base. This specification is assumed not to change with time. The cost of field labors, however, may vary with time (e.g., in response to an increase in fuel price). The cost of each type of labor is expressed in a standarized unit called UTA (Unidad Tecnológica Agropecuaria), which is equivalent to the cost of plowing one hectare of land. For example, spraying herbicide requires 0.25 UTAs. The value of a UTA initially is assumed to be constant in time and has a value of 15.5 \$ ha^{-1}.

The total direct cost per unit area associated with field labors for activity management i on production cycle t is calculated as the sum of costs for each labor type l :

$$FDC_{i,t}^{FL} = \sum_{l} \left(N_{l,i} \cdot UTA_l \cdot P_t^{UTA} \right), \quad (3)$$

where costs for each type of field labor are calculated as the product of (i) $N_{l,i}$, the number of times labor l is required by the activity/management , (ii) UTA_l, the UTA equivalent of labor l, and (iii) P_t^{UTA}, the price of labor l on production cycle t.

4.1.3.2.2.1.2 Seed costs

The costs per hectare associated with the purchase of seed s for activity management i on production cycle t are calculated as

$$FDC_{i,t}^{S} = \sum_{s} P_{s,t}^{seed} \, Q_{i,s} \quad , \quad (4)$$

where $P_{s,t}^{seed}$ is the price of seed s on production cycle t (in US dollars per kg or bag of seed), and $Q_{i,s}$ is the amount of seed s (in kg or bags of seed per ha) for activity/management i. Both the required amount of seed per ha for an activity/management and its cost are specified in the initialization data base.

4.1.3.2.2.1.3 Agrochemical costs

These costs involve all agrochemicals required by activity/management i : fertilizer (N for maize, P for soybean), herbicides, insecticides, fungicides, inoculants (for soybean), and others. The cost per ha of this component is calculated as

$$FDC_{i,t}^{AC} = \sum_{a} P_{a,t}^{AC}\ Q_{i,a}\ , \quad (5)$$

where $P_{a,t}^{AC}$ is the price of agrochemical a during production cycle t, and $Q_{a,i}$ indicates the quantity of that agrochemical used in activity/management i. The amounts and costs of agrochemicals associated with each activity/management are specified in the initialization data base.

4.1.3.2.2.1.4 Other costs

This item includes miscellaneous tasks or inputs associated with an activity/management. For example, the cost of analyzing soil samples to determine nutrient contents, or monitoring crops to assess pest or disease status. The cost per ha of this component is calculated as

$$FDC_{i,t}^{O} = \sum_{o} P_{o,t}\ N_{i,o}\ , \quad (6)$$

where $P_{o,t}^{O}$ is the price of task/input o during production cycle t and $N_{i,o}$ is the number of tasks or input o used in activity/management i. The required tasks or additional inputs associated with each activity/management and their costs are specified in the model initialization data base.

4.1.3.2.2.1.5 Economies of scale in fixed direct production costs

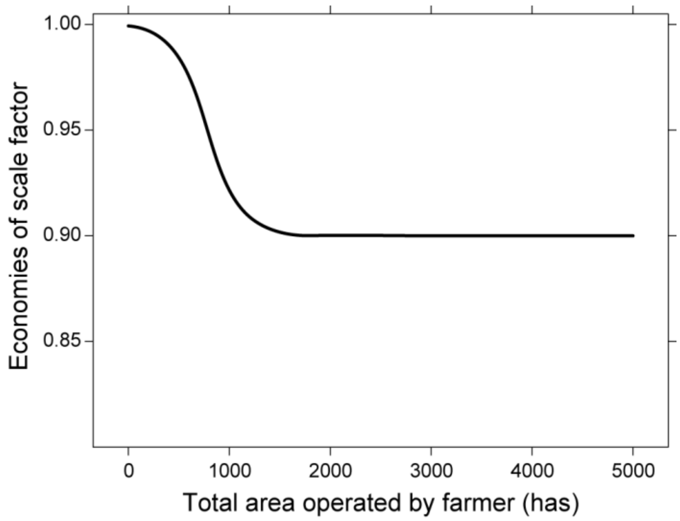
We assume that economies of scale are applicable to all fixed direct costs. The economies of scale in fixed direct costs are associated mainly with discounts in the price of inputs as the purchasing volume increases. For example, a farmer operating a large area will need to buy more fertilizer than someone with a smaller area. As purchasing volume increases (as a function of area farmed), we assume that a farmer receives increasingly higher discounts. After a certain purchasing volume, however, input costs no longer decrease: according to regional experts the maximum discount is of the order of 10%.

We calculate a factor (ESF_{FDC}) that describes economies of scale for fixed direct production costs as

$$ESF_{FDC} = 1 - \frac{0.1}{1 + \exp\left(\frac{750 - AreaOp}{150}\right)}\ , \quad (7)$$

where $AreaOp$ is the *total area operated by a farmer* (i.e., it may include one or more farms). The function is plotted in Figure 6.

Figure 6. Scale factor for economies of scale for fixed direct production costs. The factor is computed as a function of the total area operated by a farmer in a given production cycle.



4.1.3.2.2.2 Variable direct costs

Variable direct costs are those expenses associated with a particular agricultural activity/management and that depend on (or are a function of) gross income (and, indirectly, on physical yields) for that AM. The total variable direct costs for activity /management i during production cycle t are calculated as

$$VDC_{i,t} = \left(VDC_{i,t}^{H} + VDC_{i,t}^{M} + VDC_{i,t}^{T}\right) \cdot ESF_{VDC} \ , \qquad (8)$$

where the three VDC terms between parentheses in the right side of the equation correspond to the costs respectively associated with:

- Harvest;
- Marketing; and
- Transportation.

As was the case for fixed direct costs, variable direct costs are calculated separately for each activity/management. Unlike direct costs, however, the components of variable costs are not calculated per unit area, as they are a function of $GI_{i,t}$, the gross income of activity/management i during production cycle t, which already has been multiplied by $A_{i,t}$, the farm area occupied by the activity/management (see Equation 1). The following sections provide details on the calculation of each component of the variable production costs.

4.1.3.2.2.2.1 Harvest costs

This item includes the cost of harvesting a farmer's production. The harvest costs $VDC_{i,t}^{H}$ for activity/management i during production cycle t are calculated as

$$VDC_{i,t}^{H} = GI_{i,t} \cdot HF_{i} \ , \qquad (9)$$

where $GI_{i,t}$ is the gross income of activity/management i during production cycle t, and HF_{i} (no physical units, assumed to be constant in time) is a crop-dependent cost factor of harvest shown in Table 1.

Table 1. Harvest cost factor for each crop. This factor represents the proportion of the gross income from an activity/management that is needed to cover the costs of harvest.

Crop	Harvest cost factor
Maize	0.07
Soybean	0.08
Wheat	0.07

4.1.3.2.2.2.2 Marketing costs

This item includes costs associated with conditioning (e.g., drying) grain for sale, as well as commissions and fees involved in marketing a farmer's harvest. The marketing costs $VDC_{i,t}^{M}$ for activity/management i during production cycle t are calculated as

$$VDC_{i,t}^{M} = GI_{i,t} \cdot MF_{i} \ , \qquad (10)$$

where $GI_{i,t}$ is the gross income of activity/management i during production cycle t, and MF_{i} (no physical units, assumed to be constant in time) is a crop-dependent cost factor associated with marketing, shown in Table 2.

Table 2. Marketing cost factor for each crop. This factor represents the proportion of the gross income from an activity/management that is needed to cover marketing costs.

Crop	Marketing cost factor
Maize	0.08
Soybean	0.08
Wheat	0.07

4.1.3.2.2.2.3 Transportation costs

This item includes costs associated with transporting the production from a farm to the port of shipping. Transportation costs $VDC_{i,t}^{M}$ for activity/management i in farm f during production cycle t are calculated as

$$VDC_{f,i,t}^{T} = (Y_{i,t} \cdot A_{i,t}) \cdot TF_{f,i} \cdot d_f \ , \quad (11)$$

where $(Y_{i,t} \cdot A_{i,t})$ is the total production (the product of the yield per unit area and the total area dedicated to an activity/management), $TF_{f,i}$ is a farm-specific transportation cost factor (units: \$ ton^{-1} km^{-1}, assumed to remain constant in time), and d_f is the distance(in km) between farm f and the port from which grain is shipped. $TF_{f,i}$ varies for each farm because the cost of transporting one ton of grain gets lower as overall distances are larger. For now, $TF_{f,i}$ is assumed to be the same for all farms within a region, because at present distance d_f also is assumed to be constant for all farms in a region. Distance d_f has values of 100 km for farms in North of Buenos Aires (NBA) and 400 km for farms in North of Córdoba (COR).

4.1.3.2.2.2.4 Economies of scale in variable direct production costs

The current version of the model assumes that economies of scale do not apply to variable direct production costs.

4.1.3.2.3 Global (farm-wide) gross-margin

In previous sections we have shown how gross income and direct costs are calculated for each activity/management in a farm. The next step is to calculate GGM_t, the global (or farm-wide) gross margin for all activity/managements undertaken in farm f during production cycle t:

$$GGM_t = \sum_i \left(GI_{i,t} - \left(\left(FDC_{i,t} + VDC_{i,t} \right) \cdot Ma \right) \right) \ , \quad (12)$$

where $GI_{i,t}$ is the gross income for each activity/management, $\left(FDC_{i,t} + VDC_{i,t}\right)$ represents the total direct costs (i.e., the sum of fixed and variable direct costs) for that activity/management, and Ma is a factor that captures differences in the managerial ability of farmers (Section 2.3.1).

4.1.3.2.3.1 Managerial ability

Farmers' economic performance can differ substantially, even if they operate under similar production conditions and using the same production technologies (Kellerman et al. 2007). Diffferences in farmers' economic performance often are attributed to variation in their managerial ability (Nuthall 2001, Rougoor et al. 1998). Managerial ability can be understood as a farmer's ability to realize all potential costs savings.

The model includes a managerial ability factor that is assigned to a given farmer at the time of initialization, and currently is assumed to remain constant in time. The managerial ability factor Ma ranges between 0.95 and 1.05. When $Ma < 1.0$, an agent has higher managerial ability and his production costs are lower. Conversely, $Ma > 1.0$ implies lower managerial ability and higher costs. Managerial ability influences direct production costs. For example, a farmer's higher managerial ability may result in an ability to purchase inputs at a slightly discounted price, or sell products with lower marketing fees.

4.1.3.2.4 Indirect farming costs

Indirect farming costs include expenses that apply to the operation of the entire farm, and are not associated with any specific agricultural activity/management. There are five major components of indirect costs:

- Structural costs
- Management expenses
- Farm taxes
- Land rental, and
- Amortization of durable capital goods.

However, which of these components are included in the calculation of indirect costs for farm f during production cycle t depends on whether the farm is operated (i) by its owner, or (ii) by a tenant during that cycle. Table 3 lists which components must be included for each type of farm operator.

Table 3. Components of farm indirect production costs. The table indicates which component must be included in the cost calculation depending on whether the farm is operated by its owner or by a tenant.

Component is included in calculation of indirect farming costs	Farm operated by its owner	Farm operated by a tenant
Structural costs	**Yes**	**No**
Management expenses	**Yes**	**Yes**
Farm taxes	**Yes**	**No**
Land rental	**No**	**Yes**
Amortization of durable goods	**Yes**	**No**

Indirect farming costs for a farm operated by its owner are calculated as

$$IC_t = \left((IC_t^S \cdot ESF_{ISC}) + (IC_t^M \cdot ESF_{IMC}) + IC_t^{FT} + IC_t^A \right) \cdot A_f \ , \qquad (13a)$$

where the four terms between large parentheses correspond to the components of indirect costs that are included when a farm is operated by its owner (Table 3). Because all components of indirect costs are expressed in dollars per ha, the sum of cpomponents is multiplied by A_f, the total area of the farm. Note that the first two components of indirect costs are multiplied by factors that reflect economies of scale. Unlike fixed direct costs (where economies of scale were the same for all components), the factors here are specific for each component (see discussion below). Similarly, for a farm operated by a tenant, the calculation of indirect farming costs is as follows:

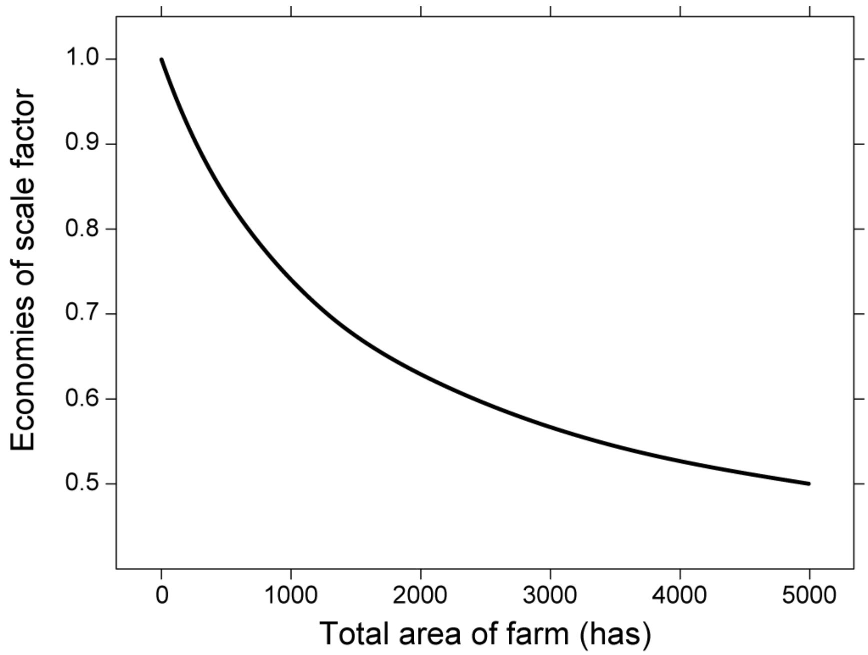
$$IC_t = \left((IC_t^M \cdot ESF_{IMC}) + IC_t^{LR} \right) \cdot A_f \ . \qquad (13b)$$

Note that in the case of a tenant, only management expenses (affected by a scale factor) and land rental are included in the calculation. The items included in each component of indirect costs and the values used in this model are discussed in the following sections.

4.1.3.2.4.1 Structural costs

This item includes costs or expenses associated with the maintenance of farm fixed structures (house, wire fences, internal roads). Other costs included in this component are farm housekeeper salary, electricity, and communications. The model currently assumes a value of 10 $ ha^{-1} for this component for the smallest farm considered (50 ha); for larger farm sizes a scale factor is applied.

Figure 7. Economies of scale factor for structural indirect costs. The factor is computed as a function of the total area of a farm.



Economies of scale are assumed to exist for structural costs. That is, as the size of a farm increases, the structural costs per unit area decrease. For example, the owner of a square-shaped 50 ha farm must maintain 2828 m of perimetral wire fencing (or 56.6 m ha^{-1}). In contrast, for a farm of 1000 ha (also assumed to be square), the perimetral fencing is 12,469 m long (or 12.6 m ha^{-1}). We calculate a factor (ESF_{ISC}) that describes economies of scale for fixed direct production costs as

$$ESF_{ISC} = \frac{0.65}{\left(A_f/1500+1\right)} + 0.35 \quad , \qquad (14)$$

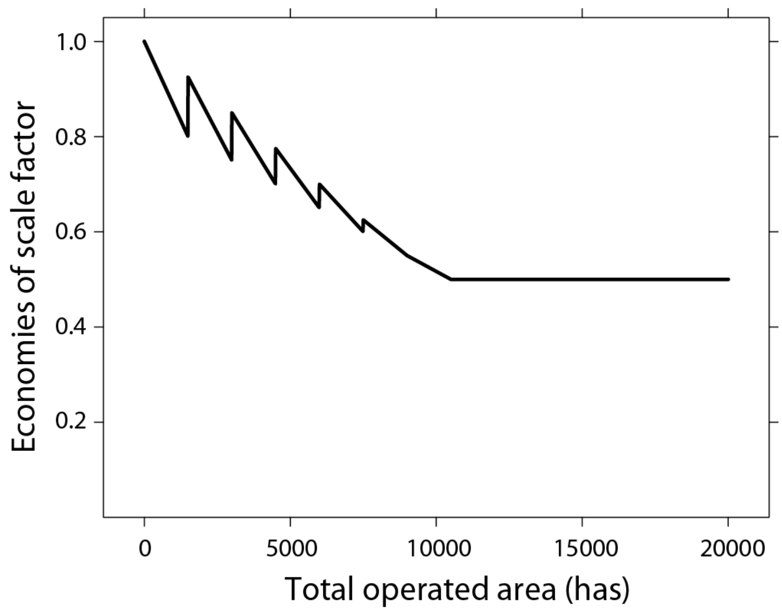
where A_f is the total area of the farm. The function is plotted in Figure 7.

4.1.3.2.4.2 Management expenses

This component includes expenses associated with the management of agricultural production activities. Items included are salaries of farm personnel (if any) dedicated to production activities, costs of operating vehicles, agronomic advice, legal and accounting advice, administrative personnel, office expenses, etc.

The model currently assumes a value constant in time of 40 \$ ha^{-1} for this component. This value, however, is multiplied by a factor that reflects economies of scale. Calculation of the scale factor shows two major differences with that performed for structural costs (Section 2.4.1). First, the scale factor is a function of *the total area farmed by the agent who operates the farm* for which structural costs are being computed. This is because management expenses can be at least partly shared among more than one farm. A second difference involves sudden jumps in management costs when the area operated by a farmer reaches multiples of a certain threshold size (currently defined as 1500 ha). According to regional experts, as farmers start operating increasingly larger areas (for example, by leasing additional land), they tend to break up the total area into separate "business units", each with its own personnel, vehicles, etc. Although the actual magnitude of economies of scale and the periodic rises in management costs must be validated with field data, the model currently implements a preliminary

Figure 8. Economies of scale factor for management indirect costs. The factor is computed as a function of the total area operated by a farmer.



calculation of factor (ESF_{IMC}) that describes economies of scale for indirect management costs as

$$ESF_{IMC} = \frac{a + (0.5 \cdot AreaOp)}{a + (b \cdot AreaOp)} \quad , \quad (15)$$

where $AreaOp$ is the total area operated by a farmer during a given production cycle. The function is plotted in Figure 8.

4.1.3.2.4.3 Farm taxes

This item includes real estate taxes (collected by the province) and road maintenance taxes ("tasa vial", collected by the departamento/partido where the farm is located). The value of this component varies between the two regions. The model currently uses constant values of 25 \$ ha^{-1} for Northern Buenos Aires and 15 \$ ha^{-1} for North Cordoba.

4.1.3.2.4.4 Land rental

This item involves the cost of leasing land from its owner; this expense is incurred only by farmers who crop land owned by someone else. The land rental cost per hectare is calculated as

$$IC_t^{LR} = RP_{f,t} \cdot P_t^{soy} \ , \qquad (16)$$

where $RP_{f,t}$ is the rental fee per hectare (expressed in tons of soybean per hectare, see Table 4) for farm f, and P_t^{soy} is the price of soybean (in US dollars per ton) during production cycle t. The rental fee $RP_{f,t}$ is a function of the soil type in a farm, which in turn is associated with the production potential of the farm. In the current version of the model, land rental fees are exogenously determined; future versions may have an endogenous price defined by a market process. The temporal evolution of both land rental fee (i.e., the required tons of soybean) and soybean prices (the second component of the rental price) is specified in the model initialization data base; in the current version both of these components are assumed to be constant in time. For the wheat/soybean double crop, we assume that land rental costs are assigned to wheat (i.e., the first crop in the wheat-soybean sequence).

Table 4. Land rental fee, expressed in tons of soybean per hectare. The fee varies with region and soil type.

Region	Soil ID and type	Land rental fee
NBA	Soil 1: Typic Argiudol	1.8
	Soil 2: Vertic Argiudol	1.6
COR	Soil 3: Typic Hapludol	1.3
	Soil 4: Entic Hapludol	1.1

4.1.3.2.4.5 Amortization of durable goods

This item includes cost of amortizing production goods lasting more than one production cycle (e.g., fencing, pastures). The current version of the model does not consider this component of indirect costs because the largest share of this expense involves amortization of farming equipment (tractors, etc.). The model assumes that all field labors are hired out and thus the operator of a farm does not own any equipment that needs to be amortized. Even if a farmer owns equipment, amortizations are often charged as part of a separate enterprise in the farm accounting.

4.1.3.2.5 Production / Operative Profits for a Farm

The production profits for farm f during production cycle t $(PP_{f,t})$ are calculated by subtracting total indirect costs (Equations 13a or 13b for farms operated by owners or tenants, respectively) from the global gross margin (Equation 12). Because we do not include amortization costs in the model (see Section 2.4.5), the operative profit $OP_{f,t}$ has the same value as production profits. To summarize, the calculation of these two quantities is as follows:

$$PP_{f,t} = OP_{f,t} = GGM_t - IC_t \ . \qquad (14)$$

4.1.3.2.6 Total Net Farming Income for a Farmer

Total net farming income is calculated by aggregating operative profits for all farms operated by a farmer during production cycle t :

$$TNFI_t = \sum_f PP_{f,t} \ . \qquad (15)$$

4.1.3.3 Other income received by a household

The total income (THI_t) received by a farmer's household during production cycle t may originate from the following sources in addition to the farming income (described in Section 2):

- Net land rental income;
- Off-farm income;
- Interests and dividends from investments; and
- Loans or credits received.

4.1.3.3.1 Calculation of net land rental income

A farmer may decide not to operate his farm on a given production cycle. This decision may result from different causes (e.g., lack of working capital, advanced age, lack of interest in farming) and is discussed in more detail in the module on update of area farmed. One assumption of this model is that a farm is rented out as a whole (i.e., the model does not allow for only part of a farm–a few plots–to be put out for rent).

If a farmer rents out his farm during production cycle t, he receives a gross rental income that depends on the size of the farm and the farm's soil type (as different soils are assumed to have different production potentials and, thus, generate different incomes). The rental fee for a farm often is defined in tons of soybean per hectare (see Table 4), therefore the actual income (in US dollars) received by a farmer depends on the rental fee stipulated in the lease, and the price of soybean during production cycle t.

The gross rental income GRI_t received by a farmer during production cycle t can be calculated as

$$GRI_t = RP_{f,t} \cdot P_t^{soy} \cdot A_f \quad , \quad (16)$$

where $RP_{r,s,t}$ is the rental fee (in tons of soybean per hectare) in production cycle t for a farm having soil type s, P_t^{soy} is the price of soybean (in US dollars per ton), and A_f is the area (in hectares) of farm f being rented. In the current version of the model, the rental fee (i.e., the number of tons of soybeans per hectare paid for land rental) is constant in time. However, soybean prices P_t^{soy} do change with time and their temporal evolution is specified in the model initialization data base.

Even if a farmer does not operate his/her own farm and acts only as a landlord, he still must bear some farm expenses. The landlord is responsible for paying structural costs associated with the maintenance of farm physical structures (e.g., farm house and other buildings, wire fencing, internal roads), but also some personnel expenses (e.g., a caretaker). Note that this expense and values used in the model are discussed in Section 2.4.1 as part of indirect production costs. The landlord also must pay farm taxes: (a) real estate taxes (collected by the province where the farm is located), and (b) road maintenance taxes (assessed by the county where the farm is located). Tax values used in the model are discussed in Section 2.4.3.

The net rental income received by the landlord during production cycle t (NRI_t) is the gross rental income minus the structural costs (SC_t) and farm taxes (FT_t) that must be borne by the landlord, multiplied by the farm area (as both types of expenses are expressed per unit area):

$$NRI_t = GRI_t - (SC_t + FT_t) \cdot A_f \ . \qquad (17)$$

4.1.3.3.2 Interests and dividends from investments

This item involves interest income and dividends from investments made with capital not used in farm production. On each production cycle, a farmer uses a large proportion (ideally, most) of his working capital in agricultural production. However, any capital not used in farming is assumed to produce an income (e.g., as if it were placed in a bank or in stocks). A realistic interest rate is assumed.

The interest income II_t received by a farmer during production cycle t can be calculated as

$$II_t = SWC_t \cdot IR_t \ , \qquad (18)$$

where SWC_t is the surplus working capital (i.e., not used in agricultural production during cycle t) and IR_t is the average interest rate offered by Argentine banks during production cycle t . *This component is not implemented in the current version of the model.*

4.1.3.3.3 Off-farm income

This is the income received during production cycle t by all members of a farmer's household from non-farming employment or work. For example, a farmer also may work as a lawyer in the town near his farm.

4.1.3.3.4 Loans or credits received

A farmer may take out a bank loan in order to increase his working capital. The amount received is considered to be part of income on a given production cycle. *This component is not implemented in the current version of the model.*

4.1.3.4 Household Expenses

Previous sections have documented how to compute costs for a given farm and income for a household (i.e., the farmer plus his immediate family). This section describes the calculation of expenses associated with a farmer's household, regardless of whether the farmer is actively engaged in farming activities (i.e., he may be renting out his own farm), or operates one or more farms. Household-level expenses include the following components:

- Personal income taxes;
- Annual household withdrawal; and
- Debt repayment.

4.1.3.5 Personal income taxes

We only consider personal income tax (IT, or "Impuesto a las ganancias" in Argentina). Income tax is paid when the total income received by a farmer or household during cropping cycle t (THI_t, see Section 3) is greater than a minimum taxable income (MTI). The MTI is calculated as the sum of a base income (BI) and personal deductions (PD) that can be claimed for (a) a spouse, (b) two children, (3) life insurance costs, (4) medical insurance costs, and (5) interests on mortgages of real estate used as a home for the household. In summary, MTI is calculated as:

$$MTI = BI + PD. \qquad (19)$$

The value of MTI was set for all agents at 8500 \$ yr^{-1} and assumed constant in time. This value of MTI was derived assuming BI = 1900 \$ yr^{-1} and PD = 6600 \$ yr^{-1}. These values were obtained from Argentina's tax authority (AFIP) and are representative of the period 2002-2007. Original values are expressed in Argentine currency and were converted to US dollars with an exchange rate of 3.15 Argentine pesos per US dollar. Although some of the deductions allowed may vary slightly with income level or family size, for the sake of simplicity we assume that deductions are the same for all agents.

For total household income $THI_t \le MTI$, a farmer does not pay income tax, i.e., IT = 0. If, on the other hand, the total income received by a farmer or household on production cycle t (THI_t) is greater than MTI then the farmer must pay an income tax IT_t. The tax amount to be paid includes two components: (i) a fixed amount FA and (ii) a variable amount; both components are proportional to the taxable income $TI_t = THI_t - MTI$ on cycle t. Morevover, both (i) the fixed component of the tax (FA), and (ii) the tax rate TR used to compute the variable component are defined for different categories of taxable income (Table 5). In summary, the income tax to be paid by a farmer in production cycle t will be calculated as follows:

$$IT_t = \begin{cases} 0 & \text{if } THI_t \le MTI \\ FA + (TI_t \cdot TR) & \text{if } THI_t > MTI \end{cases}. \qquad (20)$$

Table 5. Calculation of income tax as a function of taxable income TI_t (total household income minus minimum taxable income) in a production cycle.

For taxable income TI_t ...		The income tax will be:		
between	and	This fixed amount	Plus this percentage...	of the amount above:
0 $	3175 $	0 $	9 %	0 $
3175 $	6349 $	286 $	14 %	3175 $
6349 $	9524 $	730 $	19 %	6349 $
9524 $	19048 $	1333 $	23 %	9524 $
19048 $	28571 $	3524 $	27 %	19048 $
28571 $	38095 $	6095 $	31 %	28571 $
Over 38095 $		9048 $	35 %	38095 $

Source: Argentina's Administración Federal de Ingresos Publicos, AFIP.

4.1.3.6 <u>Household withdrawal</u>

This item includes the amount that a farmer needs to support his household expenses (housing, food, education, medical expenses, etc.) throughout a production cycle. We assume there is a minimum amount that a farmer needs to support the household ($W_{\min}$), assumed to be 18,000 \$ yr^{-1}. This amount is always "spent" by a farmer's household, even if after-tax income received is less than this figure.

As a farmer's income increases, we assume that the household expenses will also increase. If the after-tax income received in a cycle ($ATIR_t = THI_t - IT_t$) is greater than $W_{\min}$, then the farmer's withdrawal will be calculated as a function of after-tax income. The proportion of after-tax income used by the farmer to support his household is defined by a function (Figure 9) that links annual withdrawal to after-tax income averaged over the last five years, $ATIR_{avg}$:

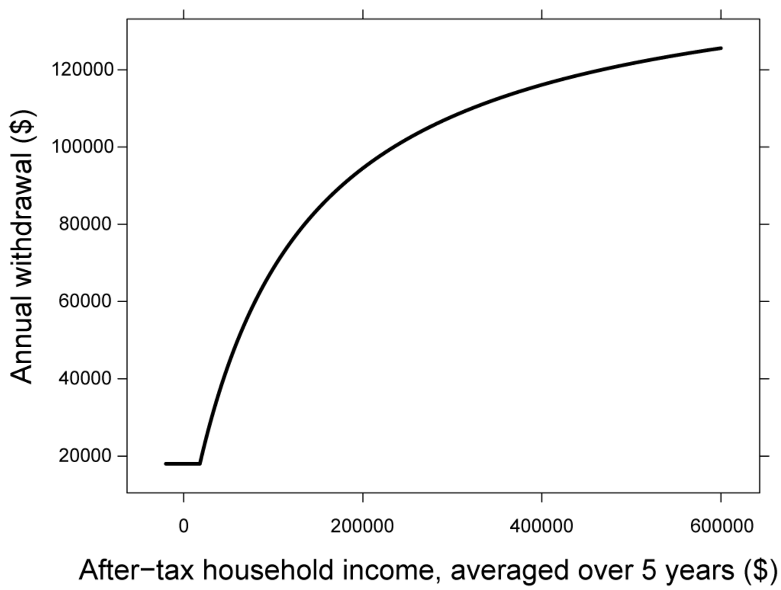
$$ATIR_{avg} = \frac{1}{5}\sum_{i=t-4}^{t} ATIR_i \,. \qquad (21)$$

The temporal averaging of after-tax income is intended to capture the effect of habituation, or getting used to a certain income over time. In summary, the household withdrawal W_t during production cycle t is calculated as follows:

$$W_t = \begin{cases} W_{\min} & \text{if } ATIR_{avg} \le W_{\min} \\ \dfrac{a + (b \cdot ATIR_{avg})}{c + ATIR_{avg}} & \text{if } ATIR_{avg} > W_{\min} \end{cases}, \qquad (22)$$

where $W_{\min}$ = 18,000 \$ yr^{-1}, and empirical parameters a, b and c have values of -324 x 10^6, 15 x 10^4 and 114 x 10^3. Parameter values were empirically determined to get the desired functional values suggested by regional experts.

Figure 9. Household withdrawal (in US dollars) for a given cropping cycle. The dependent variable is the household's after-tax income averaged over the last five cropping cycles.



4.1.3.7 Debt repayment

Debt service has not been implemented in the current version of the model.

This sub-model calculates the WC accumulated by a farmer's household at the end of a cropping cycle as the balance of (i) carried-over WC, (ii) income received and (iii) household expenses incurred during the cycle. Calculations follow standard AACREA protocols (Colombo et al., 1990). Household income can include only (a) total net farming income (TNFI) from land (owned and/or rented) operated by active farmers or (b) rental fees received by landlords. Household withdrawal – the only expense considered – is set at a constant 18,000 \$ yr^{-1} for all farmers, regardless of income level.

Calculation of TNFI involves computations at three spatial levels. First, the gross margin for an AM is calculated for each farm-plot as gross income (yield times product price) minus direct costs. Direct costs are associated with a specific AM and include fixed and variable components. Fixed direct costs do not depend on an AM's physical yield (e.g., seed and agrochemicals). Variable direct costs, in contrast, are a function of yields (e.g., harvest, marketing fees and grain transportation). Second, gross margins for all plots are aggregated into a farm-wide gross margin (FGM). Indirect costs (that apply to the farm as a whole) are then subtracted, yielding farm-level "production profits." Third, production profits are aggregated for all farms operated by an agent during cycle t : the end result is the TNFI received by a farmer. The calculation of TNFI includes realistic economies of size (Hallam, 1991; Stefanou and Madden, 1988) that introduce differences in profits among agents cropping different land areas. Cost reductions as a function of size were defined in collaboration with AACREA experts and are consistent with published reports (Díaz Hermelo and Reca, 2010).

4.1.4 Adaptation

In making risky choices, decision makers often focus on reaching a special outcome – an aspiration level or AL. Outcomes above and below the AL are respectively coded as *successes* and *failures* (Diecidue and van de Ven, 2008). By setting ALs and comparing them with performance, decision-makers seek signals about their performance that may guide future behavior (Lant, 1992). For these reasons, an AL is included in the model as a relevant component of individual choice processes.

This sub-model describes how aspirations change over time in response to experience. Our endogenous, dynamic AL adjustment is largely based on processes reported in the literature (details below). Other land-use ABMs include an AL or aspiration threshold (Gotts et al., 2003), but often it is exogenous and static. A series of AL adjustments are scheduled at different stages of a production cycle, starting from an initial value defined at the end of the previous cycle. These adjustments are briefly described in the paragraphs below. AL updates are performed for each farm, as a farmer may have separate ALs for each farm he operates because outcomes considered as successes or failures vary with the production potential of a farm's soil and climate.

A first AL adjustment (early in the cycle) is based on expected states – "favorable", "normal" or "unfavorable" – of three external context factors: climatic conditions, output prices, and input costs. For instance, if the expected climate context is "favorable", the initial AL – defined at the end of the previous cycle – is increased by 20%.

Once a farmer has made production decisions and actual contexts have been experienced, a second AL adjustment is based on comparing expected and experienced contexts. For instance, during the planning stage a farmer may expect crop prices at harvest to be "normal." If, however, commodity prices fell between planning and harvest (i.e., the context actually experienced is "unfavorable"), the previous AL may not be achievable in the updated, less favorable context. The farmer, therefore, adjusts his AL downwards. The comparison between experienced and expected states of external drivers, to our knowledge, has not been considered previously in the literature; nevertheless, the concept appears reasonable, as the context-adjusted AL weaves together a farmer's expectations of future states of the world and his own experience (Lant and Shapira, 2008).

The third AL adjustment is based on the learning and adaptation model by Levinthal and March (1981). AL for the following decision cycle (AL_{t+1}) is calculated as a weighted average of current AL (AL_t) after previous adjustments and achieved economic performance, described by farm-wide gross margin (FGM_t). That is, the current AL serves as an anchor from which incremental adjustments are made. An important cue for adjustment is the "attainment discrepancy," the difference between actual performance and aspirations $(AD = FGM_t - AL_t)$ (Lant, 1992). AL is adjusted upward when achievements equal or surpass aspirations (i.e., $AD \geq 0$), and downward otherwise (Mezias et al., 2002). This adjustment is formalized as $AL_{t+1} = \lambda\, AL_t + (1-\lambda)\, FGM_t$, where $\lambda \in (0, 1)$ describes an individual's "resistance" or "inertia" to adjusting AL (Karandikar et al., 1998). We use different λ values for positive and negative ADs (0.45 and 0.55 respectively) to reflect the fact that people "get used" to higher payoffs more rapidly than to lower ones, thus showing greater resistance to downward changes (Gilboa and Schmeidler, 2001).

As described above, both AL and AD are inherent to a particular individual. The model, however, was extended to include the influence of the physical (Moore) neighbors (Herriott et al., 1985; Mezias et al., 2002). In this approach, the average of peers' outcomes $\overline{FGM}_t^{peers}$ influences how a farmer assesses his own performance (FGM_t^{own}). If a farmer's achieved outcome is higher than his peers' average, the farmer is content and his AD will be simply $FGM_t^{own} - AL_t$. In contrast, if his peers achieve on average a higher result, then AD will be computed as $FGM_t^{adj} - AL_t$, where $FGM_t^{adj} = \gamma \cdot FGM_t^{own} + (1-\gamma) \cdot \overline{FGM}_t^{peers}$ is an adjusted outcome reflecting a weighted average of achievements for the farmer and his peers; we used γ = 0.5, as no empirical values are reported in the literature.

A final AL adjustment is scheduled at the end of a production cycle. This adjustment reflects the observation that aspirations tend to remain higher than justified by a decision maker's experience, (March, 1994). Lant (1992) speculated that this bias could be generated by optimism or overconfidence, or by motivational or strategic reasons for aspirations to consistently exceed performance. This effect is captured by an "optimism" multiplicative factor applied after all other AL adjustments are made.

4.2 Initialization

This section describes the model initialization process. All initialization data are managed through a relational initialization data base (IDB) read in at the beginning of each simulation. The scenarios explored here involve differences in the values assigned at initialization to most state variables; specific details are presented in Section 4.

Initialization of Farms. The number of simulated farms and their respective areas are specified via the IDB. Farm numbers and sizes vary among experiments; details are given below. The farms are randomly distributed on a square grid, with their position defined by X and Y grid coordinates. Each farm is assigned an owner, an initial operator and a soil type (only one soil, a typical Argiudol, is considered here). Each plot in a farm is randomly assigned an initial Activity/Management.

Initialization of Farmers. Active farmers, landlords and "reserve" farmers are created at initialization. The number of farms and total area cropped by a farmer are a result of the farm initialization step. Each active farmer is assigned an initial WC that is a function of his initial cropped area and land tenure. All farmers are assigned an initial AL of 317 \$ ha^{-1}, the average FGM per unit area for the soil modeled. Each farmer is assigned search triggering and land use selection mechanisms that remain unchanged throughout the simulation. Each farmer also is given a preference about crop rotation: two types of farmers are considered: (a) "rotators" who maintain an inflexible rotation of activities, and (b) "non-rotators" whose land allocation is not restricted by rotation considerations. Actual records indicate that adherence to rotation is strongly tied to land tenure (farmers tend to not rotate crops on rented land), thus each farmer is assigned separate rotation preferences for owned and rented land.

4.3 Input Data

This section describes the data provided as input to the model. The trajectories defined for some variables changed among scenarios; specific values used are discussed in Section 4.

Crop Yields. Time series of crop yields (in tons of grain per hectare) for each AM are provided as exogenous input. In the experiments described here we use only simplified yield trajectories for each AM: a repeating see-saw pattern of low, intermediate, high, and intermediate yields. The three see-saw levels correspond to different percentiles (e.g., 20, 50 and 80) of yields simulated for each AM using process models and the historical weather record.

Output crop prices. This input involves time series of prices of maize, soybeans and wheat extracted from the Argentine trade magazine “Márgenes Agropecuarios” (http://www.margenes.com). In all experiments we assumed constant output prices equal to median prices for 2002-2007.

Input prices. These input data involve time series of input prices (e.g., fertilizer, seed) required by each modeled AM. In all experiments we assumed constant prices for each input equal to the median value for 2002-2007. Values were extracted from “Márgenes Agropecuarios.”

Land Rental Price. This input includes a time series of land rental price (expressed in tons of soybean per hectare). Different land rental values were used in various simulated scenarios and are discussed as part of the results.

Expected and actual states of external context factors. This input includes time series of the expected and experienced states of three external context factors (Section 2.3.1.5). The possible states include three mutually exclusive conditions: favorable, normal and unfavorable. In every experiment, the expected and experienced states coincided. The only context factor varied was climate: expected and experienced climate states were unfavorable, normal and favorable for low, intermediate and high crop yields, respectively. All other contexts were kept constant and assumed as normal.

5 Model verification and validation

Verification of a model means “getting the model right.” Model validation is “getting the right model”, meaning that the correct abstract model was chosen and accurately represents the real-world phenomena. Verification and validation of ABMs deserves much attention (Fagiolo et al., 2007; Moss, 2008), but will only be briefly discussed here for the sake of space and because the experiments performed so far involve highly stylized inputs.

5.1 Verification

Verification is intended to ensure that the model implementation matches its design; it involves checking that the model behaves as expected (Crooks et al., 2008; North and Macal, 2007). After development and implementation of each component, we follow three complementary verification procedures. First, the team performs a code walk-through in which the lead programmer reads each line of code and explains its functionality. This process ensures that all design concepts and specifications be correctly reflected in the code. Second, we implement unit tests for each sub-model that run parts of the model in a controlled way (the “context” of the run is specified in the unit test). The unit tests let us compare numerical results produced by the model and an independent system. Finally, to verify that all different sub-models are working together correctly, we run the model with very few agents (order 10-15) and examine results closely (e.g., following the life history of a specific agent).

5.2 Validation

A detailed descriptions of the validation process of the Pampas Model can be seen seen in the following working paper: Pampas Model validation working paper.

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6 Model results

Initial model results can be seen in Bert et al. (2011).

Model results from simulations aimed to validate the model can be seen in the following working paper: Pampas Model validation working paper.

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