

AgriPoliS model documentation

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1 IMPLEMENTATION OF THE CONCEPTUAL FRAMEWORK OF AGRIPOLIS

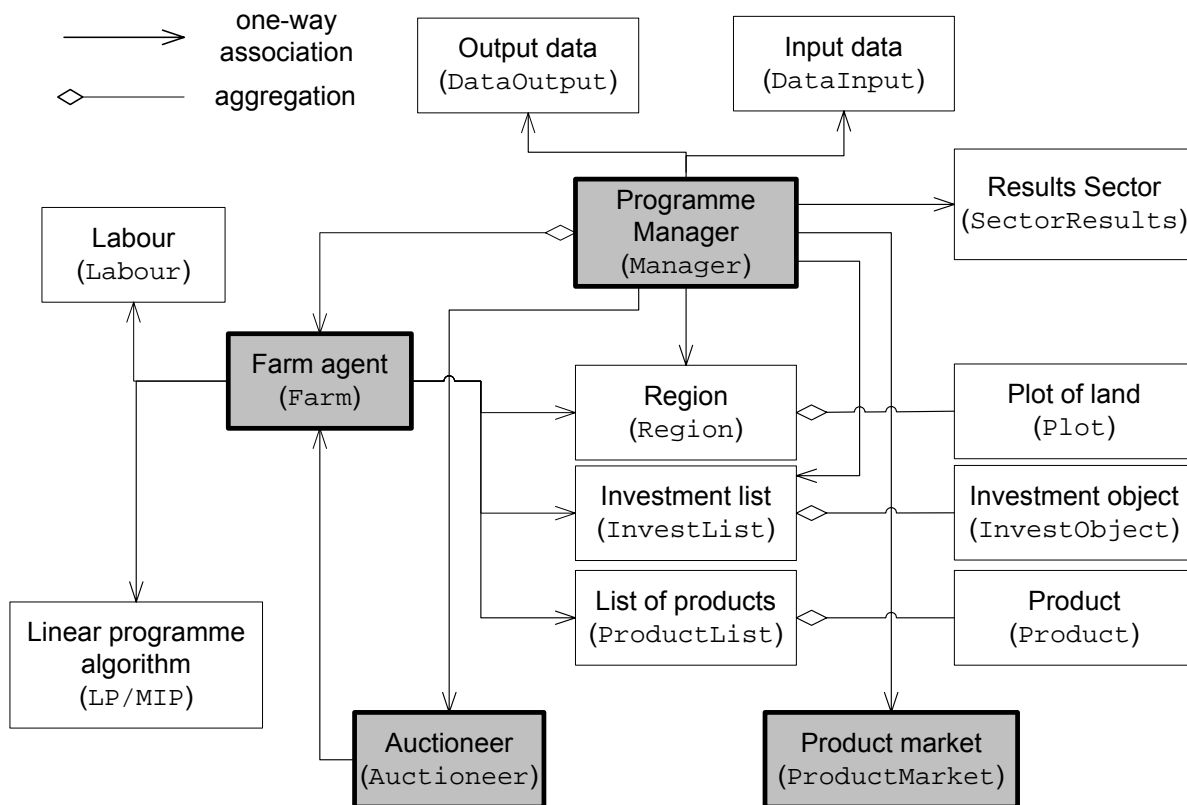
1.1 Object-oriented structure and design

The implementation of AgriPoliS conceptual framework was done using the into a computer programme is to use an object-oriented programming language such as C++, Java, or Smalltalk. Object-language C++. Object orientation provides a way to break a problem into components. In brief, object-orientation describes a system of entities in terms of elements called objects. Objects consist of data (or attributes) and actions (or methods). The data represent the state of the object. The actions operate on an object's data and change it. For example, a farm agent's investment activity (action) changes the agent's capital endowment (data). In other words, an object provides functionality in terms of data and actions.

A programme built using an object-oriented design usually contains a large number of objects, of which many are the same. For example, in an agricultural structure all objects representing farms will be treated in the same way. When designing a computer programme such as AgriPoliS using objects it is therefore sufficient to describe the behaviour of sets of similar farms as a whole. A group of objects with the same data and actions is called a *class*. Because of this, it is actually more common and useful to define the functionality of classes instead of individual objects in the design of object-oriented computer programmes. To summarise, object-oriented programmes thus consists of a set of classes, he data associated with these classes and the set of actions the classes can be asked to undertake.

To visualise and document the design of an object-oriented computer programme it is convenient to use a standardised language such as the 'Unified Modeling Language' UML (BOOCH et al. 1999). UML simplifies the representation of complex software design.

When building an object-oriented programme, one is first concerned with identifying the individual classes, then with defining the data and actions of these classes, and finally with describing the connection between classes. Figure 1-1 shows the object-oriented class design of AgriPoliS. Class names, as used in the C++ programme are in parentheses. The grey shaded classes are agent classes.

Figure 1-1: Object-oriented design of AgriPoliS

Note: Names in brackets denote the class names used AgriPoliS' C++ programme code. For reasons of clarity, the figure does not show attributes and methods. The complete model code can be provided by the author upon request.

Source: Own figure.

For the model to perform its task, it is not necessary that all classes are related with each other and can invoke each other's methods. In the figure, lines are used to express different kinds of relationships between classes. In general, a line between two classes denotes an *association* relationship. Properties of this line, such as the arrowhead, are used to specify the character of the association further. For example, the relationship between classes `Farm` and `LP/MIP` is implemented as a one-way association by using an arrow. This indicates that a `Farm` object can invoke the methods of the `LP/MIP` object, but not the other way around. Likewise, a `Farm` object determines its location by querying the `Region` object to return the position of the farm in the region, but the reverse is not possible. Another type of association is *aggregation*, denoted by a diamond. For example, the line from `Region` to `Plot` starts with a diamond, which denotes an aggregation. In this case, the region contains a set of plots. Similarly, each list of production contains a set of products.

From the classes shown in Figure 1-1, four kinds of objects can be derived: objects representing agents (`Farm`, `Auctioneer`, `ProductMarket`), objects representing production inputs and outputs (`Product`, `ProductList`, `Labour`, `InvestObject`, `InvestList`, `Plot`, `Region`), results and data management objects (`SectorResults`, `DataOutput`, `DataInput`, `LP/MIP`) and the `Manager` which controls the programme flow. Accordingly, agent objects use the functionality embodied in input and output objects to achieve their respective goals. Results and data management objects offer some auxiliary functionality in that they provide optimisation methods on the one hand, and func-

2.1 Production factors

Production factors in AgriPoliS primarily concern the classical production factors land, labour, and capital, whereby the factor capital includes both money and assets for production.

2.1.1 Land

The spatial representation in AgriPoliS is organised by way of cells, called plots (class `Plot`) of equal size. Taken together, the plots make up the entire region (class `Region`). Plots differ with respect to three aspects: land quality, usage structure, and ownership. Regarding land quality, AgriPoliS considers two qualities: arable land and grassland. Land of either quality is assumed to be homogeneous. Regarding the usage structure, agricultural utilised area classifies as either managed land or abandoned land. And finally, at the outset of the model, agricultural utilised area is either owned by farm agents or rented. All land not owned by farm agents is assumed to belong to external land owners which are not explicitly modelled. The individual plots in AgriPoliS are characterised by a number of attributes defining the plot's state, its location on the grid of plots, and its location relative to the location of the farm interested in renting the plot or the farm agent managing the plot already. A plot of either land quality can take different states:

- no agricultural use
- abandoned land currently not managed
- grassland or arable land
- plot rented by farm agent k
- plot is farmstead
- plot is owned by farm agent k .

2.1.2 Labour

Labour is supplied in three forms (class `Labour`). The first is labour supplied by the farm family. The amount of farm family labour is derived from accountancy data; it is expressed in labour units.¹ Furthermore, farms can hire additional workers either on a fixed contract basis or on an hourly basis. Hiring fixed labour is treated as an investment for a period of one year. The total labour capacity is determined in the mixed-integer programme, where variable labour and fixed labour are activities.

In addition to hiring labour, farms can also offer their own farm family labour on the labour market. This offers the possibility for non-professional farming, on the one hand, and reducing the overall farm labour if necessary on the other. Corresponding to hiring labour, fixed and variable off-farm labour activities are introduced as activities in the mixed-integer programme.

¹ One labour unit corresponds to the annual labour input in hour provided by one worker.

2.1.3 Capital

To produce, a farm agent needs capital both in the form of liquid funds to pay running costs, and in the form of fixed asset capital (investments), which determine a farm agent's productive capacity.

Investments are introduced into AgriPoliS by way of an investment catalogue (class `InvestList`). This catalogue depicts a list of investment objects containing investment possibilities and production technologies typical for the region under investigation. The investment catalogue is available to all farm agents and it provides the basis for investment decisions by the farm agents. The individual objects in the catalogue differ with respect to the type of investment (e.g. dairy, fattening pigs, machinery), as well as the size of the investment reflected in the production capacity. For each type of investment, the catalogue contains a variety of sizes. Differently sized objects affect a farm agent in three ways: First, the effect of a larger scale of production is reflected in lower average annual unit costs compared to an object of the same type, but of smaller size. Second, larger investments are also considered to have lower labour requirements relative to smaller investments.

Third, over time, the technology underlying investment objects is assumed to improve, whereby larger investment objects are assumed to be technologically more advanced. Although technological change is not modelled explicitly by way of changing the technical coefficients of production, AgriPoliS nevertheless aims to mimic two effects of technically more advanced production technologies. On the one hand, AgriPoliS assumes that with every new investment, unit production costs of the product produced with this investment decrease. The extent of this cost-saving effect depends on the technical standard of the investment (see section on cost expectations).

Stated more formally, each investment object $I_{h,i,d}$ ($h=1,\dots,H$) to produce product i ($i=1,\dots,I$) is defined by the set of attributes in Table 2-2.

Table 2-2: Investment attributes

Investment attributes
- ID-number
- Type of investment (d)
- Investment costs (€)
- Production capacity (heads or hectares)
- Maximum useful life (periods)
- Labour substitution (hours)
- Maintenance cost (% of investment costs)
- Technological change factor (%)

In particular this is the investment's type d ($d=1,\dots,D$), investment costs, production capacity, maximum useful life, labour substitution in hours, maintenance costs, and a factor representing the impact of technological change.² Maintenance costs are expressed as a percentage

² For more clarity subscripts i , and d will be omitted in the following.

of total investment costs.

The maximum time that an investment can be used in production is given by its useful life. Before any investment object has reached its maximum useful life, the object cannot be sold. Accordingly, an object's salvage value at the end of the useful life is zero such that it is non-tradable. This particular assumption has important consequences for the decision making of farm agents because it implies that investment costs are fully sunk once an investment is made. Because of this, depreciations not variable and treated as fixed costs in any case.

Capital required for production and investments is considered in three forms: short-term credit, long-term credit, and liquid equity capital.³ Short-term credit is taken up by farms in the case of short-term liquidity shortages. The amount of short-term credit is not explicitly limited but interest is higher than for long-term credit, which therefore sets a kind of natural limit for borrowing in the short-term.

Long-term borrowed capital can be used to part-finance investments. It is assumed that a maximum share $(1-v)$ of investment costs is part-financed with borrowed capital with the remaining share v representing the equity financed share. Borrowed capital for investment is supplied by an annuity credit that runs for the entire useful life of the investment. The maximum amount of borrowed capital is also not directly restricted. Nevertheless, it is assumed that a farm only invests if the equity financed share of total investment costs does not exceed a minimum equity reserve threshold MR value given by

$$\sum_{l=1}^L (v \cdot A_l) \leq L + 0.7 \cdot LA + 0.3 \cdot \sum_{l=1}^L A_{ec,l} \quad \text{with} \quad L = EC_{t-1} - LA - \sum_{l=1}^L A_{ec,l}. \quad (2.1)$$

That is, there is a limit on the maximum equity capital that can be used for investment. The limit is introduced to prevent putting the substance of the farm at risk.⁴

2.2 Production activities

Production activities in AgriPoliS are distinguished into livestock production (e.g. fattening pigs, turkeys), plant production activities (e.g. crops, sugar beets, grassland), short-term capital activities (e.g. short-term borrowing), short-term labour activities (e.g. short-term hiring), and 'additional' activities. Most livestock and plant production activities are consist of the production of marketable products. Exceptions are grassland production activities and silage maize, which serve as intermediate products for livestock production. Additional activities relate to those activities besides capital and labour which are needed to balance capacities in the short-run. This includes, for example, manure disposal, machinery contracting, or milk

³ Liquid equity capital is defined as total equity minus land assets minus equity bound in asset capital.

⁴ This means that 70% of land assets LA and 30% of total equity-financed fixed assets have to be covered by total equity capital EC_{t-1} at all times. The parameters 0.3 and 0.7 produced the most plausible results in a set of try-out simulations with AgriPoliS.

quota lease. Similar to investment objects, each individual production activity is characterised by a set of attributes (Table 2-3).

In the simulation, products are managed by the farm agents in a product list that keeps track of the total units produced as well as the gross margins associated with each product. Product prices change in response to developments on product markets (see section 4.2). Variable unit production costs are affected by technological change, on the one hand, and by the individual managerial ability of a farm agent.

Table 2-3: Product attributes

Product attributes
ID-number
Production branch (e.g. sows for breeding, dairy production)
Product produced with investment I_0 of type d
Price (€/unit)
Variable unit production costs (€/unit)
Price flexibility
Price trend (% change per period)
Support payment (direct payment) (€/unit)

3 THE FARM AGENT

To characterise the farm agent, it is useful to first describe why farm agents do what they do and based on what. That is, this section will first describe a farm agent's behaviour and the goal of its actions before describing the farm agent's actions.

3.1 Behavioural foundation

3.1.1 *Farm planning*

To model the behaviour of farms it is necessary to make assumptions about goals, expectations, managerial ability, and the variety of actions that a farm agent can pursue. AgriPoliS assumes each farm agent to maximise farm family household income in any one planning period. One planning period corresponds to one financial year. That is, a farm agent aims for maximising the total household income earned by farm family members either on or off the farm.⁵ The action space given to farm family members is defined by on-farm factor endowments (land, labour, fixed assets, liquidity), the situation on markets for production factors and products, the vintage of existing fixed assets, technical production conditions, overall

⁵ The assumption of household income maximisation is reasonable in the current version of AgriPoliS as it is applied to a region with only family farms, where the majority of the workload is done by unpaid farm family labour. If other organisational forms such as corporate farms would be considered, this particular assumption would probably need to be reconsidered to reflect potentially different goals of corporate farms.

economic framework conditions (work opportunities outside the farm, interest rate levels, access to credit), and the political framework conditions.

In order to maximise household income, farm factor endowments, production activities, investment possibilities, and other restrictions need to be brought together and optimised simultaneously. A suitable setting for this is a mixed-integer optimisation problem, the solution to which gives the optimal combination of action possibilities subject to the given framework conditions. Figure 3-1 shows matrix of the optimisation problem.

In this scheme, investments and fixed labour are considered non-divisible. They are therefore introduced as integer activities. The set of constraints consists of on-farm production capacities, but some constraints also reflect political framework conditions, such as the set-aside requirement, the limit on livestock density, or the nutrient balance. In more formal terms the mixed-integer optimisation problem is expressed as (abbreviations are given in Table 2-1)

$$\begin{aligned}
 & \max Y^e(\mathbf{x}, \mathbf{p}^e, \mathbf{c}, \mathbf{A}, \mathbf{I}, \mathbf{r}, MP, D, RE, L, BC, IC, GL, AL, MF, \dots) \\
 & \text{with } Y^e = \mathbf{x}'(\mathbf{p}^e - \mathbf{c}) + IR + S + W - RE - MC - D - OV - TC - IC - HW. \quad (3.2) \\
 & \text{s.t. } \mathbf{b} \geq \mathbf{x}'\mathbf{r} \quad \text{with } \mathbf{r} = (r_1, \dots, r_I, \dots, r_H, \dots, r_J) \\
 & \quad \mathbf{x} \geq 0
 \end{aligned}$$

This optimisation problem produces the vector \mathbf{q} of shadow prices for scarce resources. Particularly the shadow price of land q_{Land} is of interest because it provides the basis for the production of bids in the land auction (see section 3.2).

⁶ In this section, subscript k is omitted to increase clarity. All formulae concern one farm agent only.

Figure 3-1: Exemplary scheme of a mixed-integer programme matrix

Mixed-integer programme		Short term loans/saving	Buy/sell variable labour	Hire contractor	Plant production	Livestock production	Set-aside land	Buy/sell manure	Buy/sell milk quota	Investment activities	Buy/sell fixed labour
		c	c	c	c	c	c	c	c	i	i
<i>Objective function</i>		<i>Gross margin</i>									
Factor capacities	Liquidity (€)	x		x	x	x	x			x	x
	Min. equity capital reserve (€)				x	x	x			x	x
	Labour (h)		x		x	x	x	x		x	x
	Utilised agricultural area (ha)				x				x		
	Winter fodder (ha)						x				
	Livestock capacities (places)						x				x
	Machinery (ha)			x	x			x			x
Other restrictions	Organic N-balance (kg N/ha)				x	x					
	Rape seed max. (% of UAA)				x		x				
	Sugar beet max. (% of UAA)				x						
	Set aside (% of UAA)				x		x				
	Milk quota (litres)						x		x		
	Direct payments (€)				x	x	x				
	Stocking density (LU/ha)				x	x	x				

Notes: c = continuous activities, i = integer activities.

Source: Own figure.⁷

3.1.2 General remarks about expectation formation

Production planning, investment, but also the decision to continue or quit farming is based on expectations about future developments of prices, costs, technologies, investment possibilities, and policies. In AgriPoliS, farm agents can form short-term expectations about the next planning period. However, farm agents are not capable of forming long-term expectations. With respect to all other future periods, they expect prices and costs to remain constant.⁸ By

⁷ Compared to highly differentiated and detailed farm-based linear programming models (e.g., KAZENWADEL 1999; MÜLLER 2002), the optimisation model in AgriPoliS is aggregated. In view of a very detailed representation of the farm organisation the chosen aggregation can be considered to be a rather crude simplification compared to the actual planning situation and question faced by real farms. Yet, with respect to the objective of AgriPoliS it is not the specific farming system which is of interest in this study but rather a basic representation of central organisational characteristics as well as financial/ economic considerations.

⁸ This assumption has some implications in particular for investment activity because farm agents make long-term investment decisions on the basis of short-term expectations. If farm agents would be able to articulate medium or long-term expectations, some investments probably would not be made. The introduction of long-term expectations might be desirable but currently it is limited by practical problems. It appears to be

doing so, dynamic effects resulting from expectations about the development of markets and demand developments are neglected. Farm agents also follow the same pattern of expectation formation, i.e. there is no differentiation between optimists and pessimists.

3.1.3 Price expectations

Regarding prices, a farm agent follows adaptive expectations defined in terms of the weighted geometric average of actual and expected prices.⁹ A farm agent bases all planning decisions on expected prices because actual prices are only determined at the end of a production period as a result of farm activity. The expected price of production activity i in period $t + 1$ is determined as

$$p_{i,t+1}^e = (p_{i,t}^\alpha \cdot p_{i,t}^{e(1-\alpha)}) \cdot \gamma_i^{-1} \text{ with } 0 \leq \alpha \leq 1 \text{ and } p > 0 \text{ for } i = 1, \dots, I \quad (3.3)$$

The coefficient γ controls for a price trend of production activity i , whereby prices increase (decrease) if $\gamma < 1$ ($\gamma > 1$). In AgriPoliS the actual price and the expected price in period t are equally weighted, i.e., $\alpha = 0.5$.

3.1.4 Cost expectations

A farm agent also forms expectations about production costs. With regard to cost expectations, livestock and plant production activities defined in section 2.2 are treated differently from additional production activities.

For the group of additional production activities, a farm agent forms cost expectations in the same way than price expectation, however, without the price trend. Accordingly, expected costs of additional production activities are calculated as the weighted geometric average with equal weights

$$c_{i,t+1}^e = c_{i,t}^\alpha \cdot c_{i,t}^{e(1-\alpha)} \text{ with } 0 \leq \alpha \leq 1 \text{ for } i = 1, \dots, I. \quad (3.4)$$

Cost expectations for livestock and plant production activities are determined in a different way in order to introduce the cost-saving impact of technologically more advanced production technologies (see discussion on technological change). With respect to this, it is necessary to distinguish between plant production activities and livestock production activities.

As mentioned above, it is assumed that the technological standard of production technology improves with time. Thus, with every new investment into livestock production, the expected

particularly difficult to consider short-term and long-term expectations simultaneously. The problem would be even more complex if expectations would also be made with respect to the behaviour of other farm agents.

⁹ Unlike the more common definition as the weighted arithmetic mean, the chosen definition tones down expectations for period $t+1$ if expected prices and actual prices in period t differ (cf. BALMANN 1995).

production costs $c_{i,t+1}^e$ of livestock production activity i produced with investment object I are computed as

$$c_{i,t+1}^e = c_{i,t} - f_{o,i} \cdot c_{i,t} \quad \text{with } 0 \leq l < 1 \quad \text{for } i = 1, \dots, I, \quad (3.5)$$

whereby factor f represents the size of the investment. The factor is higher for larger investments.

On the subject of plant production activities, cost savings can only be realised as a combination of larger machinery together with larger field sizes.¹⁰ Expected costs of plant production activities $c_{i,t+1}^e$ are thus a function

$$c_{i,t+1}^e = c_{i,0} - l \cdot c_{i,0} \quad \text{with } 0 \leq l < 1 \quad \text{for } i = 1, \dots, I \quad (3.6)$$

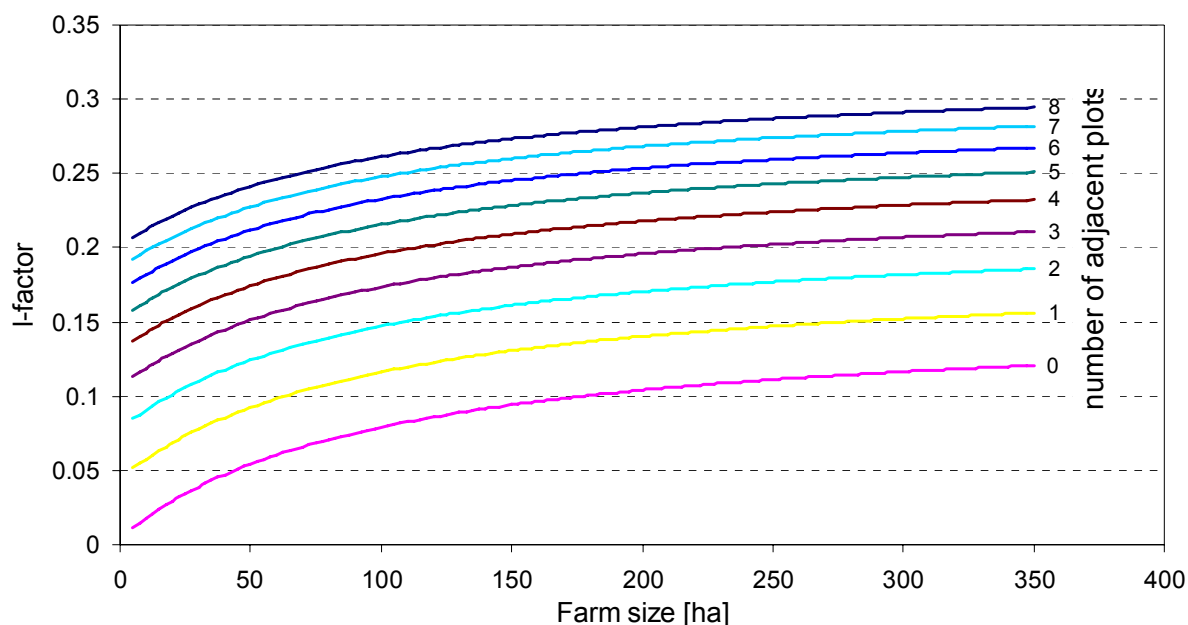
of costs at the outset of the simulation in period $t=0$, adjusted by a factor l , which is a function of the average number of adjacent plots and the size of the farm. The factor l thus captures the effect of larger field sizes. It is defined as

$$l_t = \left[1 - \frac{0.15}{1 + 100/Z} \right] \cdot \left[1 - \frac{0.45}{1 + 100/(10 \cdot AP_t + 1)} \right]. \quad (3.7)$$

Figure 3-2 shows values of l for different farm sizes and average numbers of adjacent plots. Accordingly, a farm agent with initially little and scattered land can realise large cost savings if it considerably increase its acreage. The potential cost effect is much lower if a farm agent's acreage is already high and if the plots are in the neighbourhood.

¹⁰ KUHLMANN and BERG (2002) quantify the cost difference between a 1 ha plot and one of 60 ha at 250 €/ha which corresponds to about a third of the current revenue for wheat.

Figure 3-2: Expected cost savings for machinery investments depending on farm size and the average number of adjacent plots



Source: Own figure.

3.1.5 Expectations about policy changes

When forming expectations about the next planning period, policy changes have to be taken into account as well, particularly if changes are expected to be strong. It is assumed that a farm agent knows about major policy changes one period before the policy becomes effective. This influences decision making primarily when it comes to evaluating the farm agent's profitability at the end of a planning period (see section 3.2). In AgriPoliS, no general expectation formation with regard to policy changes is implemented. Rather, depending on the policy setting to be simulated, specific assumptions and expectations have to be formulated and introduced into the model.

3.1.6 Managerial ability

In real world agriculture, the economic performance of farmers can differ substantially even if they operate under more or less the same production conditions using the same production technologies. These differences in the economic performance of farmers are often attributed to differences in the managerial ability of farmers (NUTHALL 2001; ROUGOOR et al. 1998). Managerial ability can be understood as the ability of a farm agent to use its technology to realise all potential cost savings. Accordingly, production costs are lower if managerial ability is higher. In AgriPoliS, the managerial ability of a farm agent is introduced by a factor m , which is drawn randomly from a uniform distribution at start-up. The factor affects production costs of all products in the initial period according to

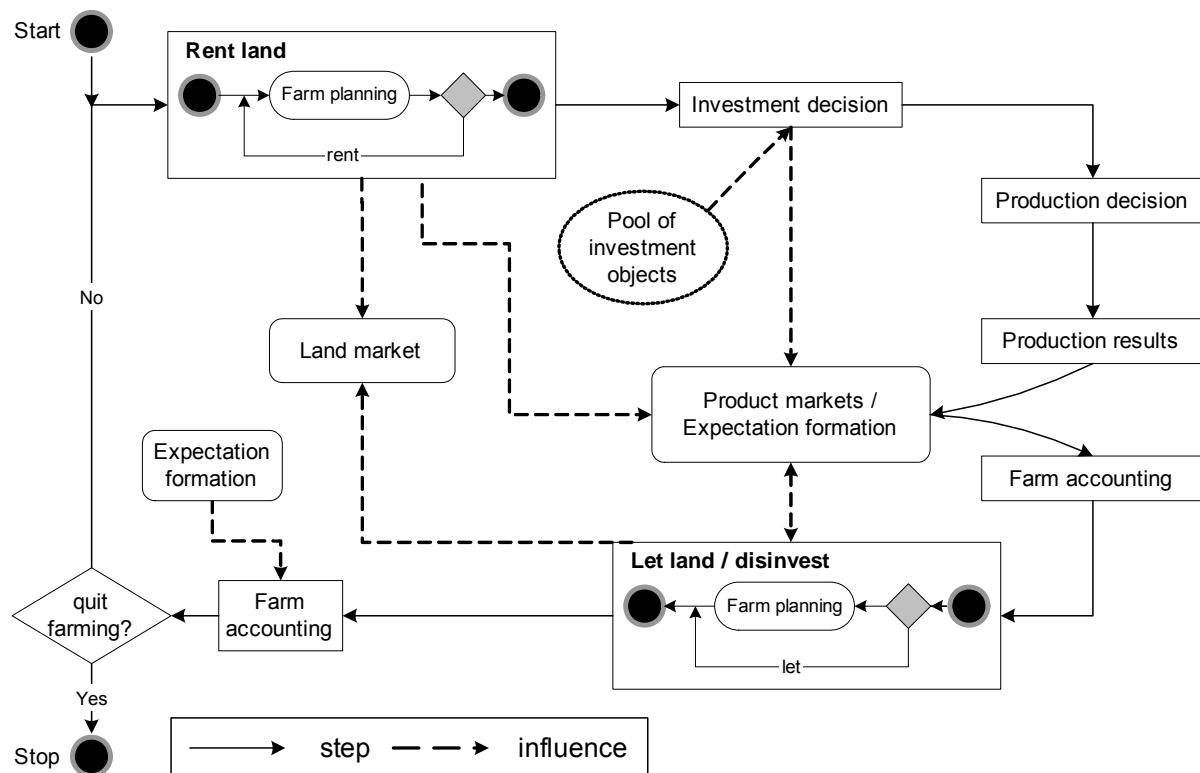
$$C_{i,0}^{new} = m \cdot C_{i,0} \cdot \quad (3.8)$$

In the current version of AgriPoliS, farm agents cannot learn to improve managerial ability.

3.2 Farm actions

During one planning period, a farm agent passes through a number of steps, shown in Figure 3-3. Each step describes an action.

Figure 3-3: Course of events in one planning period for one farm agent



Source: Own figure based on BALMANN (1995).

Based on the figure, the most important actions undertaken by a farm agent are renting land (renting additional land and disposing of unprofitable land), investment, production, farm accounting, and the decision whether to quit farming or stay in the sector.

3.2.1 Renting land

As mentioned at several points during this chapter, the land market is of particular relevance. As farms predominantly grow by renting land, AgriPoliS only considers a land rental market. In AgriPoliS, all farmland is categorised as plots of the same size. Plots are not divisible, and their size is fixed during one simulation run. Accordingly, the size of a plot defines the smallest unit by which farm acreage can change. Initially, each farm agents is endowed with a certain amount of land consisting of owned and rented land. Regarding the duration of a rental contract, no formal contract length is introduced in AgriPoliS. Instead, it is assumed that a

farm agent can terminate unprofitable rental contracts at the end of each planning period. Rental contracts for profitable plots remain valid.¹¹ Accordingly, land is available for rent either because a farm agent withdraws entirely from agriculture or because rental contracts are terminated.

In each period, land available for rent is allocated to farms in an iterative auction. In order to be eligible for renting one additional plot a farm agent is asked by the auctioneer agent to make a bid for a particular plot in the region. Assuming that transport costs and the exploitation of economies of size for machinery (see section 3.5.1) influence the renting behaviour, a farm agent aims at renting a free plot which is closest to the farmstead and next to other plots belonging to the same farm agent. The maximum price, or bid, $BID_{y,z}$ for plot $P_{y,z}$ of either land quality is a function of both transport costs $TC_{y,z}$ between the farmstead and the plot, and the number of adjacent plots T . It is defined as:

$$\begin{aligned}
 BID_{y,z} &= (q_{Land} - TC_{y,z}) \cdot \beta + T \cdot \delta & \text{for } 2 < T \leq 8 \\
 BID_{y,z} &= (q_{Land} - TC_{y,z}) \cdot \beta + \delta & \text{for } 0 < T \leq 2 \\
 BID_{y,z} &= (q_{Land} - TC_{y,z}) \cdot \beta - \delta & \text{for } T = 0
 \end{aligned} \tag{3.9}$$

with $0 < \beta < 1$.

Parameter β reduces the bid to reflect other costs associated with leasing land such as taxes, administrative costs, labour costs and fees as well as the farm agent's additional rent derived from renting this plot. Accordingly, β represents the proportion of the shadow price of an additional plot remaining with the farm agent. The higher the value of β – and therefore the higher the bid – the larger the proportion of the shadow price of land that is eventually passed on to the land owner. A higher bid also increases the probability of a farm agent to receive the plot it wishes. In this respect, the difference $q_{Land} - \beta \cdot (q_{Land} - TC_{y,z})$ can also be interpreted as a kind of security mark-up. Moreover, if the desired plot is next to other farm plots, a surcharge δ is added to the bid. If the bid is highest compared to other farms, the farm agent receives the plot.

An obvious problem with this procedure is related to the fact that the shadow price of land is only determined for one additional plot at a time. In fact, because of the indivisibility of investment options, the shadow price for land derived from the optimisation model may potentially change rapidly if calculated for more than one plot at a time. For that reason, it would be reasonable if farm agents could bid for more than one plot at a time. This poses computational difficulties, though, as different bundles of plots would need to be tested to derive the maximum shadow price from a combination of plots. Therefore, in addition to the shadow price for only one plot the average shadow price for renting eight plots at a time is calculated. The

¹¹ This assumption is quite different from rental contracts in reality, which usually involve a long-term commitment for a number of years.

maximum shadow price of one additional plot and of eight additional plots is then taken as the basis for the bid.

Similar considerations apply when a farm gives up rented land to increase its overall profitability (see section on farm accounting).¹² In this case, a farm would give up the rented plot $P_{y,z}$ if the shadow price does not cover the plot's costs consisting of the rent $R_{y,z}$ and transport costs $TC_{y,z}$, that is if

$$q_{Land} < \max_{y,z} (R_{y,z} + TC_{y,z}).^{13} \quad (3.10)$$

After giving up a plot, the farm recalculates the shadow price of land. The procedure is repeated until the shadow price of land is at least equal to the costs of a plot. Unless a farm agent withdraws from agriculture altogether, it is not possible to let owned land in order to be rented by other farm agent.

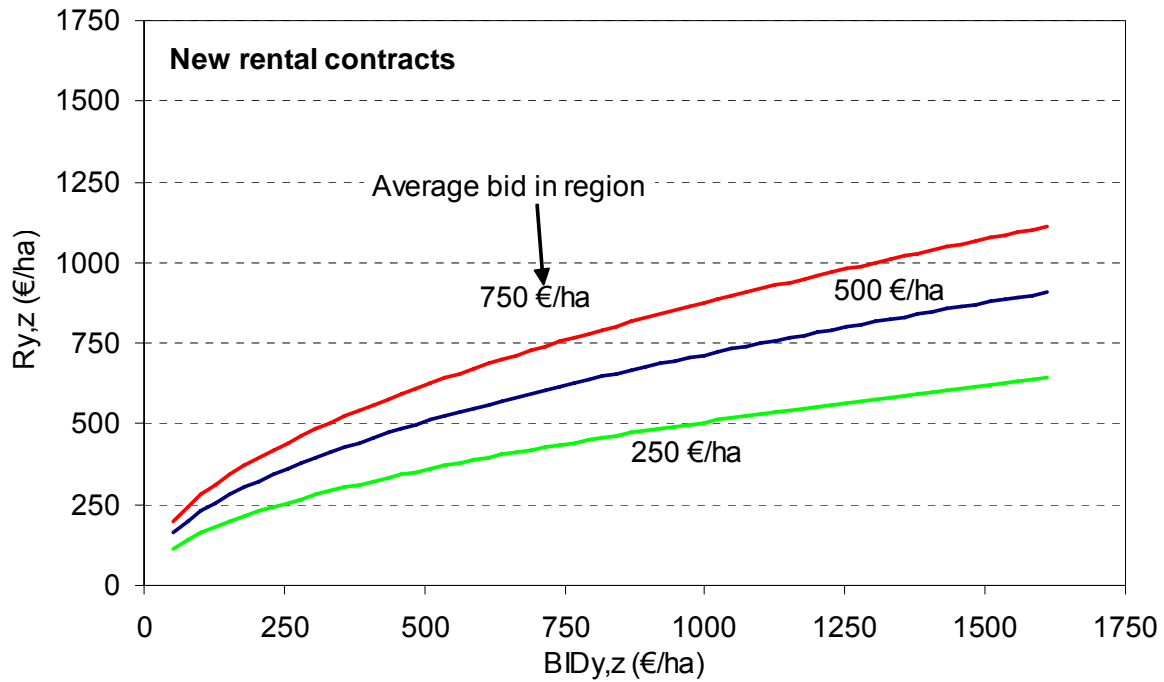
In AgriPoliS, the rent paid for a plot is not equal to the bid given in the land auction. This has two reasons. The first is that shadow prices can vary significantly between farms. Hence, rents would differ significantly between farms, which would affect the farm agent's competitiveness. The second reason is that an equality of bids and rental prices is rather unrealistic. In reality, most new rental contracts include a passage that places rents in the context of an average regional rent. To reflect this, the actual rent paid for a newly rented plot is calculated as

$$R_{y,z} = \sqrt{BID_{y,z} \cdot \bar{R}}, \quad (3.11)$$

i.e., is it derived from the weighted geometric average of the bid $BID_{y,z}$ given in the auction and the average regional rent \bar{R} with equal weights. Figure 3-4 shows this relationship graphically.

¹² Here, the number of adjacent plots is not taken into account.

¹³ Adjacent plots are not considered when rental contracts are terminated.

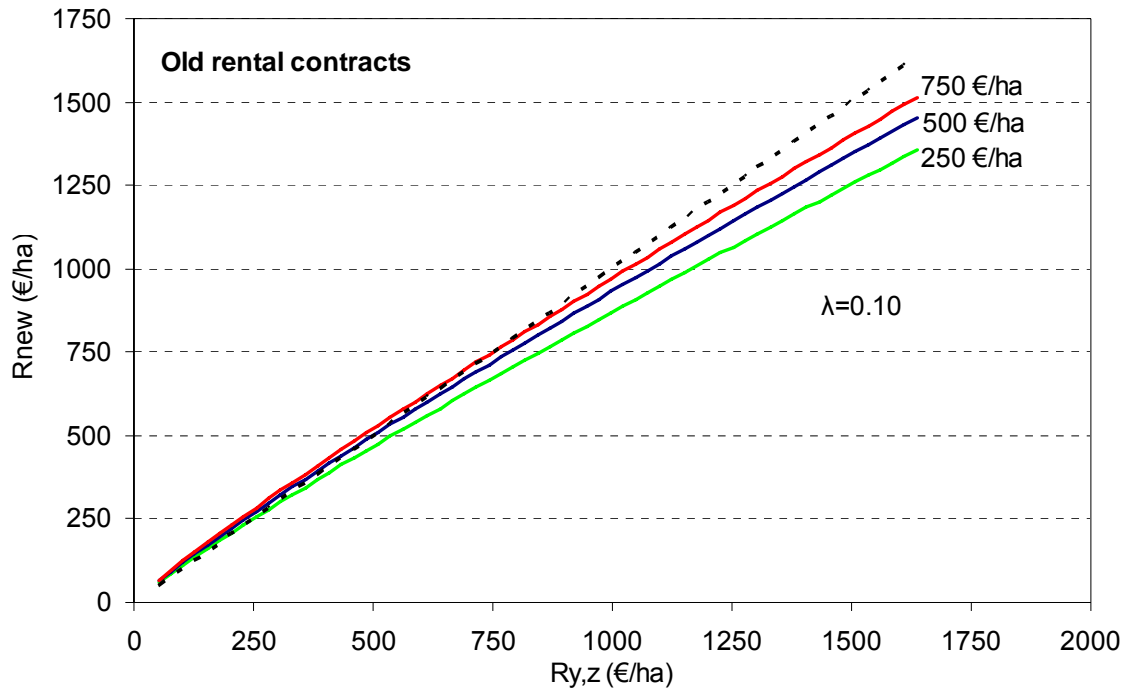
Figure 3-4: Rent adjustment for new rental contracts

Source: Own figure.

As it is often the case in reality, also the rent fixed in older rental contracts is adjusted. Frequently, such an adjustment is due to strong product price changes, policy changes, or changes in the regional reference rent. In AgriPoliS, the adjusted rent $R_{y,z}^{new}$ for old contracts is the weighted geometric average of the average rent in the region and the previous rent of the plot

$$R_{y,z}^{new} = \bar{R}^{\lambda} \cdot R_{y,z}^{(1-\lambda)}, \quad (3.12)$$

whereby the weight λ is given by the share of newly rented land in the entire region. Depending on λ and the average regional rent, the adjusted rent develops close to the initial bid. This is plotted in Figure 3-5.

Figure 3-5: Rent adjustment for old rental contracts assuming 10% newly rented plots

Source: Own figure.

3.2.2 Investment

Farm investment activity is typically concerned with the purchase of machinery, buildings, facilities, and equipment. As investment and production are mutually interdependent, they are considered simultaneously in the mixed-integer planning programme presented in section 3.1.

Investments in AgriPoliS take place in two steps, investment planning and the actual investment. In the first step, the farm carries out planning calculations based on the farm planning problem presented in section 3.1. During the planning calculations, be it in the context of renting land or for production, a farm agent takes investment opportunities into account. However, during all planning calculations the agent does not invest in real terms but plans 'as if' he invested, i.e. production capacities are not actually changed. The number, kind, and combination of investments are not restricted. In principle, a farm agent only invests in one object or a combination of objects if the expected average return on investment, determined in the farm-planning problem, is positive, i.e. if total household income increases. For investment-planning purposes, all expenditures and payments related to an investment are distributed equally over the investment's useful life and considered in the optimisation. Accordingly, the average annual costs AC_h of investment $I_{h,i}$ considered in the objective function of the farm-planning problem are calculated as

$$AC_h = A_h \left[(1 - v) \cdot CRF_{i_{bc}, N_h} + \frac{v}{N_h} + MC_h \right]. \quad (3.13)$$

Maintenance costs MC_h are expressed as a percentage of total investment costs. The average annual opportunity costs of equity capital bound is determined as

$$A_h \cdot v \cdot f, \quad \text{with} \quad f = \frac{(1+i_{ec})^{N_h}}{(1+i_{ec})^{N_h} - 1} - \frac{1}{N_h \cdot i_{ec}}. \quad (3.14)$$

Only in the second step, based on the planning calculations, the actual investment activity takes place (see Figure 3-3) resulting in a change of production capacities. After investment, depreciation and repayment are determined as shown further down in Table 3-2.

3.2.3 Production

Each farm agent is assumed to optimise production in any one planning period subject to available production capacities using the planning approach described in section 3.1 above. All production activities enter the optimisation as continuous activities. That is to say, products are assumed to be fully divisible.

In addition to fixed assets (buildings, machinery, equipment), production requires liquidity to cover running costs in the short-run. Products produced continuously throughout the year (mostly livestock production) have a constant demand of working capital, which in AgriPoliS is defined as liquid assets. Other products such as crops are seasonal products and therefore require working capital only during parts of the year. To overcome short-term liquidity short-ages, farm agents can take up loans to finance working capital.

3.2.4 Farm accounting

The financial year of a farm agent ends with an annual financial statement. This statement produces indicators on incomes and profits, the stability and financial situation of the farm agent, and the remuneration of fixed factors. Table 3-1 lists central indicators and how they were derived; Table 3-2 shows this.

shows a list of selected variables in the financial statement.

Table 3-1: Indicators calculated in the financial statement

Indicator (end of period t)	Calculation
Profit (farm income) (t) =	Gross margin + Interest on working capital + Subsidies - Rent paid - Current upkeep of machinery and equipment - Depreciation - Farming overheads - Transport costs - Interest paid - Wages paid
Household income (t) =	Profit + Off-farm income
Farm net value added (t) =	Profit + Rent paid + Interest paid + Wages paid
Equity capital (t) =	Equity capital (t-1) + (Household income - Withdrawal)

Change in equity capital is an indicator of a farm agent's economic stability. A farm is economically more stable the higher the equity-debt ratio of the farms, i.e. the higher the share of equity capital in total capital. Consequently, it would be reasonable for a farm to stop farming if equity capital is less than zero. In this case, all own resources, which could be used, for example, as credit security are used up.

Accumulation of equity capital is the result of balancing total farm income with living expenses. In AgriPoliS, the equity capital stock increases because total household income is greater than withdrawals. Regarding withdrawals, it is assumed that each family labour unit working on the farm consumes at least WD_{\min} per year. A share ε of the remaining farm household income after deducting WD_{\min} is consumed in addition to the minimum withdrawal. The remaining share $(1 - \varepsilon) \cdot (Y - WD_{\min})$ is then charged to the farm agent's equity capital. Table 3-2 shows this.

Table 3-2: Definition of selected variables used in the financial statement

Variable (at end of period t)	Definition
Equity capital	$EC = EC_{t-1} + Y - WD$
Withdrawal	$WD_{\min} \leq WD \leq (Y - WD_{\min}) \cdot \varepsilon + WD_{\min}$ with $0 < \varepsilon \leq 1$
Gross margin	$GMA = \mathbf{x}'(\mathbf{p} - \mathbf{c})$
Interest on borrowed capital	$IC = f(BC, i_{BC})$
Repayment	$RP = (1 - \nu) \sum_{c=1}^S [A_c \cdot (1 + i_{bc})^{(n_c-1)} \cdot (CRF_{i_{bc}, N_c} - i_{bc})]$
Long-term loans	$BC = BC_{t-1} - RP + BC^{new}$
Depreciation	$D = \sum_{c=1}^S [A_c \cdot (1 + i_{bc})^{(n_c-1)} \cdot (CRF_{i_{bc}, N_c} - i_{bc})]$ $+ \sum_{c=1}^S [A_c \cdot (1 + i_{ec})^{(n_c-1)} \cdot (CRF_{i_{ec}, N_c} - i_{ec})]$
Farming overheads	$OV = \gamma \cdot GMA$ with $\gamma \leq 1$
Current upkeep (maintenance)	$MC = \sum_{c=1}^S MC_c$
Rent paid	$RE = \sum_y \sum_z R_{y,z}$
Transport costs	$TC = f(DI_{y,z})$
Liquidity ^{a)}	$L = EC_{t-1} - LA - A_{ec}$
Interest on working capital	$IR = i_{ec} \cdot L$

Note: a) Liquidity is updated throughout the accounting year whenever the total equity capital stock changes due to investment or disinvestment.

Lasting farm profitability requires that all farm-owned production factors (own land, family labour, liquid equity capital, and quota) receive an adequate payment when used on-farm. To assess farm profitability, all on-farm production factors have to be valued at their opportunity costs (Table 3-3). Since costs of fixed assets are assumed sunk, they are not considered in this calculation. In the case of handing over the farm to the next generation, opportunity costs of labour are also higher if a farm is handed over to the next generation. This reflects the comparable industrial salary a successor could potentially earn if he/she would not take over the farm. Accordingly, a successor would only take over the farm if the farm were able to generate income that is at least as high as the opportunity costs.

A decision on whether to quit is necessary subject to the expected household income in future periods. As mentioned above, the planning horizon of a farm agent is one period. Hence, the calculation of expected household income takes account of investment possibilities and off-farm employment possibilities in the next period. Moreover, expected household income rests on the assumption that a farm agent's land endowment does not change. The resulting expected household income is contrasted with the opportunity costs of all on-farm production factors.

Table 3-3: Opportunity costs of production factors

Factor	valued at
Farm family labour	Off-farm income
Labour of farm successor	Comparable industrial salary
Working capital	Long-term savings rate
Owned land	Average regional rent
Milk quota	Quota price

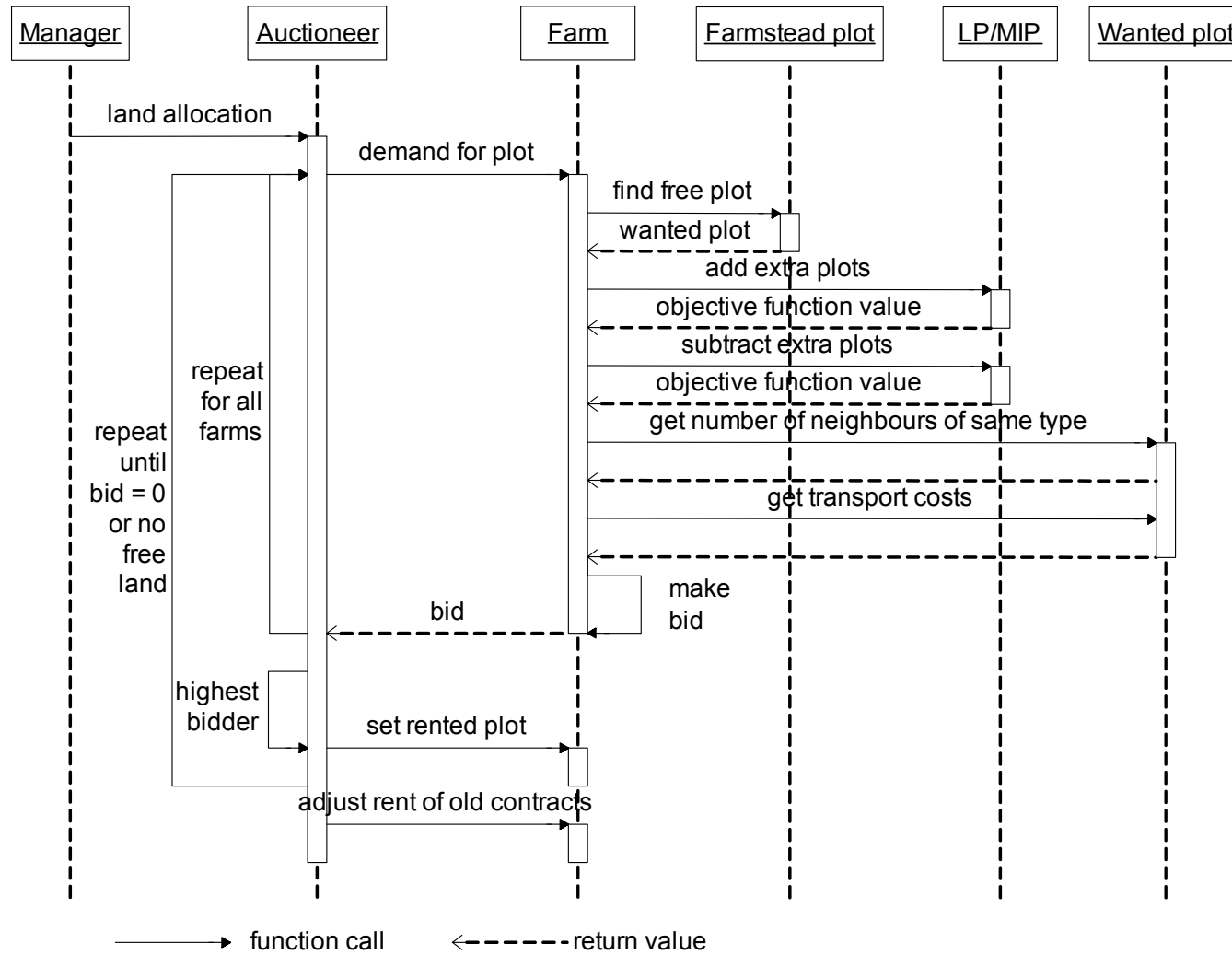
If expected household income does not cover opportunity costs, it is rational for the farm to quit and use all production factors outside the farm. This decision rule defines a clear threshold between quitting and staying. In some instances, it may be reasonable to blur this threshold, for example, by introducing a tolerance margin in which farms stay in business despite of higher opportunity costs.

4 FACTOR MARKET AGENTS

4.1 Land auctioneer

Compared to a farm agent, the auctioneer is a very basic kind of agent. The auctioneer coordinates the auction of free plots by collecting bids from farm agents; it then compares the bids, and finally allocates a free plot to the highest bidder. The auctioneer acts on behalf of land owners who are not engaged in farming, but receive all rent payments. The exact auction process is illustrated in Figure 4-1 using UML notation.

Figure 4-1: Sequence diagram of the land auction using UML notation



Source: Own figure.

According to this figure, the order of events is the following: Triggered by the `Manager` class, the auctioneer carries out an iterative auction of free plots. It does so by asking each farm agent intending to rent additional land to produce a bid for one plot. As discussed in section 3.2, the farm does so by first searching for a free plot closest to the farmstead. It then determines a bid for that plot based on a combination of the shadow price of land, the number of plots adjacent to the desired plot, and transport costs. Following, the auctioneer ranks the bids and allocates the desired plot to the highest bidder. As farm agents can only bid for one plot at a time, the bidding procedure continues until all plots are allocated or the highest bid is zero. In a final step, the auctioneer determines the actual rental price that is to be paid for the plots just allocated. In addition to setting the price for new rental contracts, the auctioneer also initiates the price adjustment of old rental contracts by applying the rent adjustment procedure shown in section 3.2. This ends the land allocation procedure.

4.2 Product market

The product market agent determines a market price for all produced outputs in any one period. For this, the market agent makes use of a number of price functions. The demand function for agricultural products in `AgriPoliS` assumes neither a fully elastic nor a fully static demand. In analogy to the function for gross margins developed in `BALMANN` (1995), it is assumed that for most products of products i the price in period t is a function

$$p_{i,t} = p_{i,0} \cdot \gamma_i^{-(t+1)} \cdot \left(\frac{\sum_k X_{k,t}}{\sum_k Z_{k,t}} \right)^{-b_i} \quad \text{with } k = 1, \dots, K, \quad (4.15)$$

where $p_{i,0}$ denotes the initial price of product i at the outset of the simulation (period $t=0$), the coefficient γ_i controls for a price trend over time, and the last term allows for price variation in depending on the cumulative quantities produced by K farm agents. The parameter $b_{i,t}$ represents price flexibility which is equivalent to the inverse demand elasticity (cf. `BALMANN` 1995).

The price function differs for selected products. In particular this is:

- *Piglet production:* Piglets are assumed to be used as intermediate inputs in fattening pig production. For this reason, the total quantity of piglets produced is reduced by the quantity of piglets used for fattening pig production.¹⁴
- *Milk quota:* Since the year 2000, prices for milk quota in Germany have been determined in quota auctions. Implementing such an auction would be a complex matter (comparable to the land auction). Regarding quota, `AgriPoliS` therefore implements a highly simplified quota market in that it reflects only the results of quota auctions. In principle, farms can

¹⁴ At the current development stage, there is no interdependence between the price of piglets and the gross margin of fattening pigs.

buy and sell quota indefinitely. But, to keep milk production within realistic limits, the price of quota is related to a regional reference quota.¹⁵ If milk production is above (below) the regional reference level plus a 10% tolerance, the quota price rises (falls) by a given percentage. The quota market as implemented in the model resembles a quota leasing market. To prevent quota from leaving the region, the marginal revenue of selling quota is less than the marginal revenue of buying additional quota.

- *Manure trading*: Regarding manure trading, farm agents generally pay to dispose of excess manure, on the one hand. On the other, farm agents receive payments for taking excess manure up to a given limit. Manure trading is not limited to the region. That is why in the simulation there may be more farms taking up manure than farms disposing of manure and vice versa. Similar to the market for milk quota, the price of disposing manure rises the more excess manure is offered.

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¹⁵ The regional reference quota is calculated as the total number of dairy cows in the region to be modelled times the average milk yield in that region. A tolerance range of $\pm 10\%$ around the regional reference quota is assumed, so that it does not function as the exact threshold value for price changes.