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Implementation and analysis of 'satisficing' as a model for farmers' decision-making in an agent-based model of groundwater over-exploitation

Bachelor Thesis

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Abstract

The representation of decision-making poses one of the main challenges in agent-based farming models. Different approaches on how to model farmers' decision-making exist. In many agricultural economic models the rational utility-maximizing farmer is assumed and often profit is used as a substitute for utility.

However, simple observations of land-use suggest that this assumption is not true in most cases. The literature contains a wide range of alternative models of farmer decision making. One classical strategy in the decision-making literature is Simon's concept of 'satisficing'. Yet this concept has been little used by those researching agricultural innovation.

In this work the concept of 'satisficing' is implemented as a model for farmers' decision making in an agent-based farming model, that deals with groundwater over-exploitation in the 'Mancha Occidental Aquifer', Spain.

One aim of this work is to learn about the influence of alternative decision-making models on simulation results. Furthermore this work exemplifies a way, how a rather theoretical concept such as 'satisficing' can be transformed into a feasible decision-making model for agent-based farming models. Finally results of this model are compared to empirical data and to results of the base model, in order to find out, if an implementation of satisficing as a model for farmers' decision making delivers more realistic results.

Main findings of this work are, that the implementation of satisficing has a considerable influence on model results, particularly concerning the diffusion process of innovations and farmers' responses to laws and policies. Furthermore it is concluded, that the concept of satisficing has its strengths and weaknesses but overall does not lead to more realistic results. At the same time a number of assumptions are necessary in order to create a feasible 'satisficing' decision-making model. It is expected that the choice of those assumptions influences model results to a large extend.

In sum this work delivers new insights into alternative modelling of decision-making and reinforces case specific questions concerning irrigation in the 'Mancha Occidental Aquifer'.

Zusammenfassung

Die Abbildung von realen Entscheidungsfindungsprozessen stellt eine der großen Herausforderungen in agenten-basierten Landwirtschaftsmodellen dar. Es existieren verschiedenste Ansätze zur Modellierung von Entscheidungen der Landwirte, wobei vielen Modellen ein rational handelnder, profit-maximierender Bauer zugrunde liegt. Oftmals wird zusätzlich der Begriff des Nutzens über den Profit definiert und somit ein profit-maximierender Farmer angenommen.

Einfache Beobachtungen zeigen jedoch, dass diese Annahme in vielen Fällen nicht mit der Realität übereinstimmt. In der Literatur sind eine Reihe von alternativen Modellen zur Entscheidungsfindung von Bauern vorhanden. Eine klassische Strategie in diesem Bereich stellt Simon's Konzept des 'Satisficing' aus dem Jahre 1955 dar. Jedoch kam dieses Konzept im Bereich der Modellierung von agrarwirtschaftlichen Innovationen bis jetzt selten zum Einsatz.

In dieser Arbeit wird 'Satisficing' in einem existierenden agenten-basierten Landwirtschaftsmodell zu Grundwasserübernutzung im "Mancha Occidental Aquifer" in Spanien implementiert.

Ziel der Arbeit ist es, Erkenntnisse über den Einfluss einer alternativen Modellierung des Entscheidungsfindungsprozesses auf die Modellresultate zu erlangen. Weiterhin soll ein möglicher Weg aufgezeigt werden, ein eher theoretisches Konzept, wie das des 'Satisficing', in ein brauchbares Modell zur Entscheidungsfindung in einem agenten-basierten Modell zu übertragen. Zuletzt sollen Ergebnisse dieses Modells mit empirischen Beobachtungen und den Ergebnissen das Basis Modells verglichen werden, um Erkenntnisse darber zu gewinnen, ob die Implementierung von Satisficing zu realistischeren Resultaten fhrt.

Haupterkenntnisse dieser Arbeit sind, dass die Anwendung von 'Satisficing' als ein Entscheidungsmodell für Farmer in diesem Modell einen deutlich Einfluss auf die Modellresultate hat. Dies gilt insbesondere für den Diffusionsprozess von Innovationen und die Reaktionen der Landwirte auf sich ändernde Richtlinien und Gesetze. Weiterhin wurde deutlich, dass das Konzept des Satisficing Stärken und Schwächen hat, insgesamt aber nicht zu realistischeren Resultaten führt. Es wurde schließlich aufgezeigt, dass eine Reihe von Annahmen notwendig sind, um eine brauchbare Modellierung des 'Satisficing' zur Entscheidungsfindung zu implementieren. Es wird erwartet, dass die Wahl und konkreten Ausprägungen dieser Annahmen die Modellresultate und -dynamiken zu einem großen Umfang beeinflussen.

Alles in allem liefert diese Arbeit neue Erkenntnisse zur Modellierung von alternativen Entscheidungsmodellen und verstärkt einige spezielle Fragestellungen hinsichtlich der Bewässerungsentwicklung im "Mancha Occidental Aquifer".

1 Introduction

The representation of decision-making is one of the main challenges in agent-based farming models (Schreinemachers and Berger, 2006). In the past, research on decision making and behaviour among farmers has been dominated by economic concerns. In many agricultural economic models the rational utility-maximizing farmer is taken for granted and profit is often used as a substitute for utility - the rational profit-maximizing farmer is assumed (Wallace and Moss, 2002; Edwards-Jones, 2006). However, simple observations of land-use suggest that this assumption is not true in most cases (Edwards-Jones, 2006). Thus recent research on land-use has put more emphasis on the importance of understanding the decision-making of human actors (Schreinemachers and Berger, 2006).

In agent-based farming models there is a growing interest in modelling decision-making based on the concept of 'bounded rationality' (e.g. Parker et al. (2002); Edwards-Jones (2006)), including heuristic agents, that neither have the information to compare all feasible alternatives nor the computational power to select the optimum. A classical strategy within this domain is Simon's concept of 'satisficing' (see Simon (1955, 1957, 1993)). In this concept the decision maker continues seeking a solution only until he finds one that is 'good enough' (Gotts et al., 2003), "instead of hopelessly searching for the best“ (Simon, 1990, p. 17).

However, Simon's concept is yet little used by those researching agricultural innovation (Gotts et al., 2003). In the following work, Simon's concept is applied to an existing agent-based farming model, implemented by Holtz (2009), which constitutes the base model for this work. It aims at investigating the history of irrigated agriculture in order to learn about influence of farmers' characteristics on land-use change and associated groundwater over exploitation (see Holtz (2009)). It is applied to the case of the Mancha Occidental aquifer in the Upper Guadiana Basin, Spain.

In the base model decision-making of farmers is modelled by means of a utility function. Potential land-use pattern are evaluated based on different factors, including their economic return, their associated risk, their labour needs and their legality. In this work, 'satisficing' is implemented as a model for farmers' decision-making in that model.

The Upper Guadiana is a typical case of pumping-based socio-economic development, that resulted in a non sustainable situation of groundwater over-exploitation (Martinez-Santos et al., 2008). Since the 1970's the availability of new irrigation technologies led to an increase of irrigated area and to a change of farming practices towards water-intensive crops. Different legal regulations and subsidy schemas were introduced to reduce the amount of groundwater extractions by farmers. However, many farmers did not and still do not accept pumping restrictions and take more water than granted (Llamas and Martinez-Santos, 2005). In order to successfully develop policies for a sustainable water future, it is hence required, to get an improved understanding of land-use change (Holtz, 2009).

In this work, first the case of the Upper Guadiana Basin is presented (chapter 2). Following an overview of research on decision-making is given, particularly focusing on models to represent decision-making in agent-based farming models (chapter 3). Thereupon the theoretical backgrounds of Simon's concept of 'satisficing' are described. Chapter 4 presents an overview on how this concept is applied to the specific agent-based farming model, that constitutes the base model for this work. Simulation results are shown in chapter 5 and discussed in chapter 6. Finally the main findings are summarized in chapter 7.

2 The Upper Guadiana Basin

The Upper Guadiana Basin (UGB) is an area of approximately 16,000 km^2 located in "Castilla La Mancha" in central Spain. Climate conditions are continental and semiarid, long dry periods alternate with short wet sequences (Llamas and Martinez-Santos, 2005). An average rainfall of 415 mm/yr in this region means that the UGB is one of Spain's driest areas (Lopez-Gunn, 2003).

By 2003 the UGB was home to about 500,000 people. Since the population density is very low in this region and most people live in municipalities below 150 inhab/km^2 the UGB is classified as a rural area. Per capita income in the UGB is significantly below Spain's and Europe's average and thus the UGB has been on the receiving end of European subsidies (Llamas and Martinez-Santos, 2005).

The UGB is divided into six different hydrogeological units whereas the Mancha Occidental aquifer (MOA) is the main unit in terms of size, capacity and socio-economic importance (Lopez-Gunn, 2003). Agriculture plays an important role in the MOA, by 2000 it accounted for 38% of the employment in this region (Llamas and Martinez-Santos, 2005). Additionally a significant industry is linked to agriculture (e.g. wineries, food, pumps, well-drilling and irrigation system industries).

During the last four decades agriculture has undergone massive changes in the UGB, when new cheap drilling and pumping techniques became available for farmers. The use of groundwater offered significant advantages over traditional surface water diversion practices: it is individually available for all farmers independent of extreme weather conditions such as droughts (Martinez-Santos et al., 2008). Hence, since the 1970's, the irrigated area has increased and farming practices have changed towards water-intensive crops, which return more profit. This has led to an over-exploitation of groundwater resources (Llamas and Martinez-Santos, 2005). By 1990 groundwater irrigated area had increased to approximately 130,000 ha in the UGB, compared to approximately 30,000 ha in the 1970's (Martinez-Santos et al., 2008; Holtz, 2009). Today, groundwater-dependent agriculture is the main water consumer in the MOA, accounting for more than 90% of the total water use (Lopez-Gunn, 2003).

The effects of uncontrolled aquifer withdrawals were soon felt, in some areas the drop in aquifer levels reached 40 and 50 meters (Lopez-Gunn, 2003). This led to a significant loss of groundwater-dependent ecosystems in the UGB (Martinez-Santos et al., 2008).

On the other hand the use of groundwater has led to significant positive socio-economic changes in this region. As Martinez-Santos et al. (2008, p. 513) states: "Formerly a depressed and scarcely populated area now boasts one of the most dynamic economies of the Castilla-La Mancha Region." Nevertheless, the increasing welfare in this region happened at a significant environmental cost and raised concerns as to its sustainability.

From the mid- to late 1980s on, different water policies were implemented (see Lopez-Gunn (2003); Llamas and Martinez-Santos (2005); Martinez-Santos et al. (2008); Varela-Ortega (2007)). In this work the following formal rules are considered:

Vine law (up to 1996):
Irrigation of vineyards has been forbidden in Spain up to 1996.

Water Act (1985 onwards):
Declaration of groundwater as a public good; implementation of pumping quotas.

Common Agricultural Policy (CAP) (1993 onwards):
Compensatory payments for reduction in prices of different crops.

Agro Environmental Programme (AEP) (1993 onwards):
Payments were offered for farmers, who voluntarily reduced water use.

Many farmers did not accept pumping restriction and given, that the Guadiana Water Authority didn't have the human or economic means to control all farmers, an estimated 20,000 - 30,000 illegal wells were operational by 2002 (Llamas and Martinez-Santos, 2005; Martinez-Santos et al., 2008). Additionally the CAP favoured the appearance of water-intensive crops at some times (Martinez-Santos et al., 2008).

Concerning the participation of farmers, the AEP appeared to be more successful. From 1993 onwards farmers were offered compensatory payments for different levels of reduction on water use (50%, 70% or 100%). The majority of farmers in the area joined the first AEP, by 1997 almost 90% of irrigated land came under this programme. Water abstractions were reduced by 60% (Varela-Ortega, 2007). However, a main drawback of the programme was its high cost. Modulations of the programme in 2001 and 2003 reduced compensatory payments especially for big farms and withdrew the 70%- reduction option (Varela-Ortega, 2007). Thus the programme was abandoned by the majority of farmers after 2003 (Varela-Ortega, 2007).

Figure 2.1 shows the irrigated area and groundwater extractions in the MOA from 1978 to 2005. Until 1988 estimated extractions increased up to more than 500 Mm^3 year. As a response to new policies and in particular to the AEP extractions dropped to a sustainable amount by 1995. However, in the following years extractions increased again and until now a non-sustainable level of extractions is maintained.

It should be noted that historical data on land-uses and water usage is scarce and uncertain in the UGB. Until the mid 1980's there was little control or monitoring through the government and even 20 years later registers are still incomplete (Holtz, 2009). Additionally there is a high amount of illegal wells (Martinez-Santos et al., 2008) and overall illegal irrigation plays a major role in the UGB. Thus data on water extractions, irrigated crops and the irrigated area is uncertain. Nevertheless data on irrigated crops is available. Figure 2.2 shows the available empirical data concerning irrigated crops, that constitutes a base for calibrating and evaluating. Although these data have to be interpreted carefully, some qualitative conclusions are possible. Despite their low profitability, cereals and vineyards dominate. After 1995 the are of irrigated horticultural crops stays comparatively low while irrigated cereals and vineyards increase.

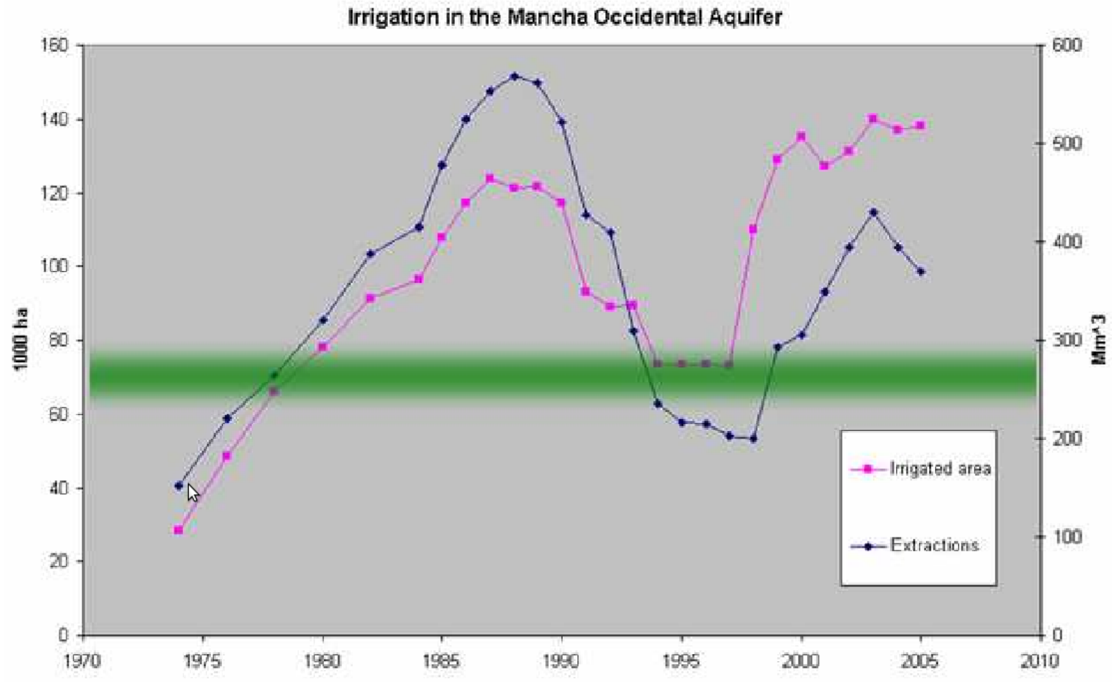

Figure 2.1: Irrigated area and water extraxtions in the MOA. Estimated renewable water ressources are represented by the shaded area (source: Holtz (2009)).

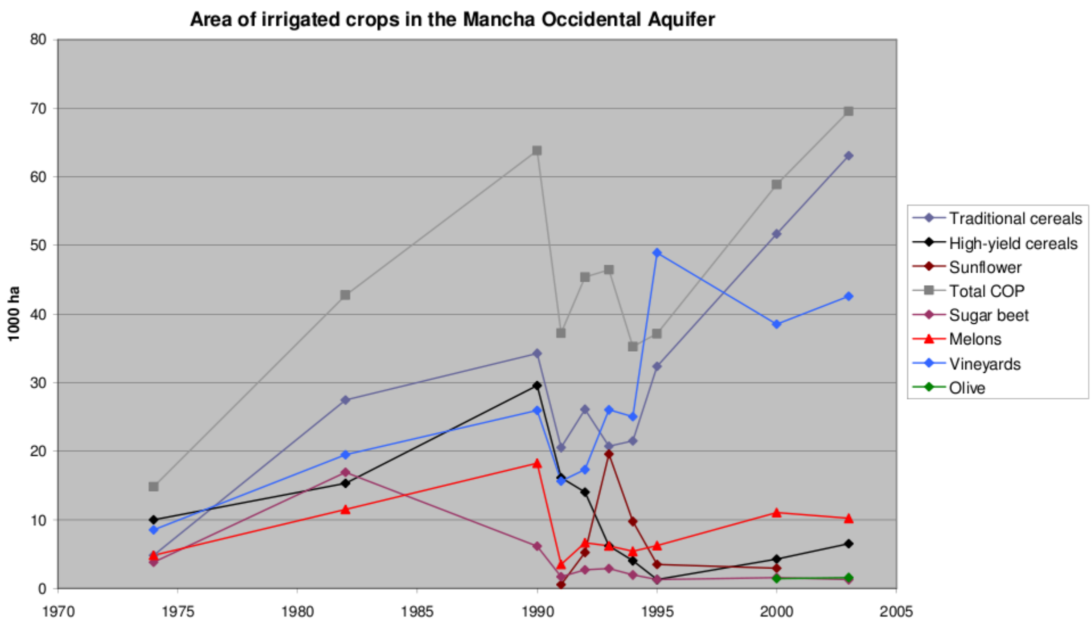

Figure 2.2: Area of irrigated crops in the MOA (source: Holtz (2009)).

3 Decision-making

The following chapter displays findings about modelling decision-making, particularly focusing on models to represent decision-making in agent-based farming models. Two converse concepts of rationality are explained and finally Simon's concept of 'satisficing' is introduced.

Assumptions about how people take decisions form the basis of empirical research and simulation models dealing with diffusing innovations (Schwarz, 2007). Modelling individual decision-making poses an important challenge, since underlying dynamics of this process are unobservable (Parker et al., 2001). Different decision-making models or different sets of parameter can produce the same outcome (Parker et al., 2001). Thus validation of decision-making models is difficult.

Modelling decision-making plays an important role in particular in agent-based models. According to Hare and Pahl-Wostl (2001) a significant source of uncertainty in the outcome of agent-based models can arise from uncertainty about which decision models to use.

Related to farming models Matthews et al. (2007) argue, that one reason for the poor use of such models as decision support tools is the poor understanding by researchers of the actual process of decision-making by farmers. Recently research on land-use and land cover change has put more weight on understanding the decision-making of human actors. As Schreinemachers and Berger (2006, p. 30) state: "The challenge becomes how to represent real world land use decision-making."

In the following two opposite concepts of rationality are displayed: rationality in the neoclassical sense and bounded rationality. Assigned to agent decision architectures, it is distinguished between optimizing agents and heuristic agents. While Schreinemachers and Berger (2006) argue that there is more of a continuum between heuristic and optimizing behaviour, some significant differences between those concepts can still be found. There upon Simon's concept of satisficing is described and the adaptation of this concept in this model is explained. All in all the literature contains a wide range of models for farmers decision-making. However, this work is mainly concerned with the specific concept of satisficing and hence not all feasible decision-making models for farmers are discussed in the following.

3.1 Rationality in the neoclassical sense

An ideal image of a decision maker, the so called 'homo oeconomicus', forms the foundation of neoclassical economy. The homo oeconomicus contains the following characteristics (Schwarz, 2007):

- The homo oeconomicus maximizes his utility at any time.
- Preferences meet the criteria for rationality (e.g. completeness, transitivity) and they are constant over time.
- The homo oeconomicus has full information about all potential alternatives and their outcome.
- Finally the homo oeconomicus has the cognitive power to evaluate all information about all potential alternatives.

Traditionally models that use that concept of rationality employ a utility function to define what is best. Yet utility is very hard to measure in real world situations and therefore it is difficult to use this concept in a more practical manner (Edwards-Jones, 2006). In many agricultural economic models with rational utility-maximizing farmers, profit is used as a substitute for utility - the rational profit-maximizing farmer is assumed (Wallace and Moss, 2002; Edwards-Jones, 2006).

However, observations of land-use suggest that this assumption doesn't hold in most cases (Edwards-Jones, 2006). Recent studies have concluded that farmers have different objectives and attitudes and that farmers' decisions are not always aimed at the unique goal of profit (Wallace and Moss, 2002; Willock et al., 1999). Therefore different variables (e.g. risk-aversion of farmers) have to be taken into account when modelling farmers' decision-making process.

Nevertheless optimizing agents, who maximize their utility, still imply complete rationality. They are able to select the 'best' decision from a range of potential alternatives, while the selection process itself is assumed to be costless (Schreinemachers and Berger, 2006). Once the agent doesn't have full information we deviate from the neoclassical concept.

3.2 Bounded rationality

"Because of the limits on their computing speeds and power, intelligent systems must use approximate methods to handle most tasks. Their rationality is bounded." (Simon, 1990, p.6).

Bounded rationality occurs if one of the following stipulations is not met (Schwarz, 2007; Simon, 1955):

- The set of alternatives is completely known to the decision maker.
- The outcome of all alternatives is known to the decision maker and their utility can be evaluated.
- The decision maker maximizes utility.

In reality humans' cognitive restrictions don't lead to the optimizing behaviour as assumed in the neoclassical economy (Simon, 1990). In contrast humans decision-making often happens under limited computational power and irrational preferences.

Many authors prefer the use of bounded rationality when building agent-based farming models (e.g. Parker et al. (2002); Edwards-Jones (2006)). When assuming bounded rationality agent's decisions are often based on heuristics. The heuristic agent in contrast to an optimizing agent decides on the basis of simplified rules, which are adopted to the decision problem. Heuristic agents neither have the information to compare all feasible alternatives nor the computational power to select the optimum (Schreinemachers and Berger, 2006). Goldstein et al. (2001) show that under different circumstances simple heuristics such as "imitation", "take the best" or "take the first" are able to perform very well in reality.

3.3 Satisficing

Satisficing is a classic strategy in the decision-making literature (Payne and Bettman, 2000) that forms an alternative to optimizing strategies and goes back to Herbert Simon (Simon, 1955, 1957, 1993). Simon criticised primarily the neoclassical assumption that all information is available to a decision maker and that the cognitive search process is costless. Based on this criticism he developed the concept of satisficing.

In this concept alternatives are evaluated sequentially, in the order in which they appear in the choice set. "Instead of hopelessly searching for the best" (Simon, 1990, p. 17) the decision maker continues seeking a solution only until he finds one that is 'good enough' (Gotts et al., 2003). A solution is considered as being good enough (satisfactory) if it meets the needs of the situation and the aspirations of the decision maker; as soon as a satisfactory solution is found, it can be accepted (Simon, 1993).

The aspiration level, that determines what is satisfactory, can be multidimensional. The value of each attribute under consideration is evaluated to find out whether it meets the aspirations of the decision maker. If any attribute fails to meet these aspirations, the option is rejected (Payne and Bettman, 2000).

The amount of time and computation required to find a satisfactory solution will generally be far less than the time and computation to find the solution of the optimization problem. According to Simon (1993, p. 883) "the empirical evidence is overwhelming that people (...) typically satisfice rather than optimize".

In this work satisficing has been implemented in an agent-based farming model of groundwater over-exploitation. As stated before aspiration levels (thresholds) of farmers are multidimensional and flexible. However, the satisficing approach provides no guidance as to how these levels are to be specified (Stirling et al., 2002). It seems to be difficult to find good and practically feasible thresholds without first exploring the limits of what is possible, that is, without first finding optimal solutions (Stirling et al., 2002).

Aspiration levels of people are influenced by former experiences and by comparison with others (Schwarz, 2007). In this model farmers' thresholds are therefore adjusted according to former outcomes of farmers' land-use patterns (history adjustment). Since in this model no social network is implemented the adjustment of thresholds by comparison with others is difficult. Referring to Simon (1993, p. 883) "people tend to aspire for a future that is little better than the present" and "(...) they also aspire to outcomes as good as or a little better than the outcomes for others." Between 1960 and 2009 the gross domestic product (gdp) of Spain increased almost every year (Maddison, 2008) and it is assumed that farmers in the UGB want to be part of this economic growth. Thus a yearly increase of the aspiration level for economic returns (farmers' profit thresholds) is implemented in this model.

The satisficing concept doesn't assure that overall a satisfactory solution will be found (Schwarz, 2007). Decision makers, who are forced to take a decision but unable to find any satisfactory solution have two options: extending their search area or redefining what is satisfactory for them, with other words decreasing their aspiration level (Schwarz, 2007). In this model both of those options are considered. If the current situation is not satisfactory anymore, farmers extend their search area for alternative land-use pattern. If all of those alternatives are considered not satisfactory, one threshold of a farmer is decreased.

The way these threshold-adjustments are implemented is described in chapter 4.

4 Model description

4.1 General setup

The base model for this work is an agent-based model implemented to investigate the history of agriculture in the Upper Guadiana Basin in order to learn about farmers' characteristics on land-use change and associated groundwater over-use in this region (Holtz, 2009). The model focuses on the farming level, one agent represents a farm. Agents are classified in three different types:

- Part-time farms
- Family farms
- Business farms.

Farmers of different types vary in their average farm sizes, maximum labour force and available family labour. Concerning farm sizes there are five different classes:

- Very small (4 ha, mostly part-time farms)
- Small (8 ha, mostly family farms)
- Medium1 (32 ha, mostly family farms)
- Medium2 (70 ha, mostly business farms)
- Big (150 ha, mostly business farms).

One step in the model represents one year in reality. The simulation covers a period from 1960 to 2009. Each step farmers have to decide on their land-use pattern. A land-use pattern is defined as a combination of different land-uses. A crop combined with an irrigation technology is an option, whereas one option together with its releated area forms a land-use. In total the model contains nine different crops: traditional cereals (wheat, barley), sunflower, high yield cereals (maize, alfalfa), sugar beet, vineyards, olives, melon, paprika and garlic and four different irrigation technologies (flood-, sprinkler-, drip irrigation or rainfed). Overall there is an amount of 23 options (not all combinations of crop and irrigation technology are feasible) (Holtz, 2009).

In this model a self-reinforcing diffusion process of innovations is implemented. Any irrigation technologies and some crops (e.g. horticultural crops) are unknown to farmers at the beginning of the simulation. In their choice process farmers consider unknown options with some probability, which is positively related to the overall use of this option.

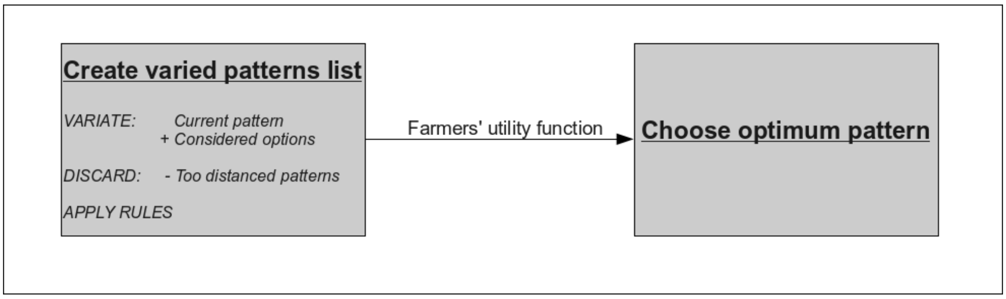

Figure 4.1: Decision making process of the base model.

Farmers' response to policies and innovations is contingent to the specific situation of a farm; decision making of single farms is path-dependent (Holtz, 2009). Farmers have knowledge about some crops and technologies, unknown options require learning efforts and might result in fewer yields in the learning period. A take up of unknown land-uses usually includes loss of capital ("sunk cost") and new necessary investments. Path dependency is considered in different ways in this model. First farmers build up stocks of irrigation technologies and improve their knowledge about used technologies and crops. Moreover potential new land-use patterns are created by varying the current land-use pattern. Finally a "difference-function" is implemented that filters away all land-use patterns which are considered as being too different to the current land-use pattern.

In this model prices for crops are exogenous and adjusted to empirical data. Different formal rules are implemented in this model:

- EU- Common Agricultural Policy (CAP) (1993 onwards)
- Water Act (1985 onwards)
- Vine law (up tp 1996)
- Agro Environmental Programme (AEP) (1993 onwards).

See chapter 2 for further information on these formal rules.

4.2 Decision making process of the base model

"The way farmers derive next year's land-use patterns is essentially at the heart of this model (...)" (Holtz, 2009, p.16). The base model's decision making process is shown in figure 4.1.

A list of varied pattern is created and according to the utility-function the best pattern is chosen. The creation of the varied pattern list is an important part of the decision-making process and includes different steps (see figure 4.2).

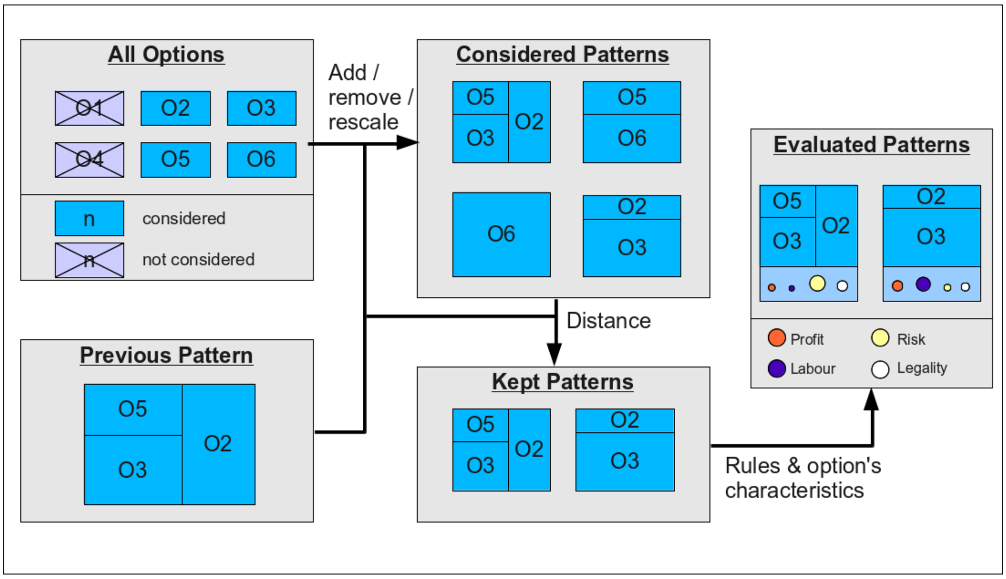

Figure 4.2: Creation of the "varied patterns list" (own figure based on: Holtz, unpublished).

As mentioned in the last section potential future land use patterns are computed by varying the current land-use pattern. The current pattern of a farmer is varied by adding new (considered) options, removing options or rescaling used options. Each step 1000 varied patterns are computed that way. Note that hence farmers don't have perfect information since not all possible land-use pattern are included in the decision making process. In any case the current pattern is always part of the varied pattern list. Once the varied patterns list is created, all land-use patterns that are considered as being "too different" to the current pattern are discarded[1]. Finally rules are applied to the remaining land-use patterns whereupon those patterns are evaluated on the four scales profit, labour, risk and legality. "Profit" refers to the (expected) econmic return of the land-use pattern, "labour" refers to associated labour needs. "Risk" is associated with the standard deviation of the econmic return and "legality" shows to what extent this land-use pattern may violate laws.

In the base model a utility-function appears at this point and farmers choose their "best" pattern from all considered ones. The utility function is different for each farmer type (e.g. profit is more important for business farmer than for part-time farmer). In the base model the following seven main parameters exist for each farmer type:

- γ describes the impact of profit on utility
- ρ describes the impact of risk on utility

[1]See Holtz 2009 p.55 - 58 for more detailed information on the distance function

- λ describes the impact of legality on utility
- κ represents the maximum labour force to which the farm is extendable
- The family labour that is available on the farm
- α_s determines how frequently "distant" land- use patterns are discarded relating to knowledge and prior experiences (skills)
- α_c determines how frequently land- use patterns are discarded relating to sunk costs and necessary investments (capital)

4.3 Decision making process of the satisficing model

In the satisficing model no utility function is implemented. Instead farmers' decisions are based on individual thresholds. For each of the scales profit, labour, risk and legality a threshold is implemented. Potential land-use patterns are judged as "satisfactory" or "not satisfactory". A solution is considered satisfactory if and only if all thresholds are reached.

4.3.1 Evaluation of land-use patterns

The base model contains functions that compute the output of a land-use pattern (p) on the four scales mentioned above. The functions for profit (g), labour (w) and risk (r) are adopted from the base model (Holtz, 2009, p.20). In the base model the function for evaluating legality (l) only returns true (legal behaviour) or false (illegal behaviour), which is not considered very useful for the use of thresholds. Thus l has been redefined. The legality function includes two laws and is dependent on the land-use pattern (p) and on the farmer (f). The function is composed of a legality value concerning the "water law" (w) and a legality value concerning the "vine law" (v). The water law allocates water rights for each farmer (amount of allowed extractions).

From 1986 onwards w is defined as follows in this model:

$$w(f,p) = \begin{cases} min(1, \frac{water_{rights}\ (f)}{water_{used}\ (p)}) & \text{for } water_{used} > 0 \\ 1 & \text{for } water_{used} = 0 \end{cases}$$

The vine law forbids irrigation of vineyards. Up to 1996 v is defined as follows in this model:

$$v(p) = \frac{area\ _{irrigated\ vine}\ (p)}{area\ _{total}\ (p)}$$

Those two values lead to the new legality function:

$$l(f,p) = \frac{w(f,p) + v(p)}{2} \tag{4.1}$$

Note that $w(f,p) = 1$ before 1986 as the water law is not yet in force and $v(p) = 1$ after 1997 when the vine law is out of force (and therefore $l(f,p) \geq \frac{1}{2}$ in those periods).

4.3.2 Adjustment of thresholds

As the model consists of repeated decisions and the output for farmers changes over time (e.g. profit is higher once farmers start to irrigate) and experience influences aspiration levels, thresholds have to be flexible. In this model thresholds are adjusted by past outcomes, by a yearly profit threshold increase and by the success of finding a solution.

The adjustment to past outcomes (history adjustment) happens as follows: The average of the outcomes of the past five years (a_i) is computed for each of the four scales profit, labour, risk and legality. Each step (t) a threshold (τ_i) is adjusted in a way that the difference of the average past outcome and the current threshold is decreased, which means that a threshold which is higher than the average output will be decreased and vice versa. The parameter μ constitutes an inertia of this adjustment:

$$\tau_{i,t+1} = \tau_{i,t} + \mu(a_i - \tau_{i,t}) \; ; \quad \mu \in [0,1],\ i \in \{1,2,3,4\} \tag{4.2}$$

For $\mu = 0$ no history adjustment takes place, for $\mu = 1$ all thresholds are equal to their average of the past five years. Note that the profit threshold is increased additionally independently of history.

A yearly increase by ω of the profit threshold (τ_p) is implemented. This can be motivated by several aspects (see chapter 3 and 6). This increase happens previous to the history adjustment. Each step (t) farmers' profit thresholds (τ_p) adjust relating to the average outputs of the past five years (a_p) and the yearly profit increase ω. The adjustment of the profit threshold happens as follows:

$$\tau_{p,t+1} \;=\; \tau_{p,t} \cdot (1+\omega) \;+\; \mu(a_p - (\tau_{p,t} \cdot (1+\omega))) \tag{4.3}$$

$$\Leftrightarrow \quad \tau_{p,t+1} \;=\; \tau_{p,t} \cdot (1+\omega)(1-\mu) \;+\; \mu(a_p) \; ; \quad \mu \in [0,1],\ \omega \geq 0 \tag{4.4}$$

Equation 4.4 reveals that for $\mu = 1$ no yearly profit increase takes place since thresholds are equal to the average outcome of the past five years.

Finally thresholds are decreased in this model if a farmer evaluates all of the potential future land-use pattern as not satisfactory. In this case one threshold is randomly chosen and decreased by the factor δ. This decrease happens as follows:

$$\tau_i \;=\; \tau_i(1-\delta) \; ; \quad \delta \in \,]0,1],\ i \in \{1,2,3,4\} \tag{4.5}$$

4.3.3 General procedure of decision making

Figure 4.3 shows the general course of decision making. In the first step the profit threshold increases and the history adjustment of thresholds take place. Then the current pattern of a farmer is evaluated. If the current pattern is considered satisfactory (all thresholds are reached) the farmer has found a solution and the decision making process ends. If the current pattern is not satisfactory anymore (at least one threshold is not reached) a list of varied patterns is created in the same way as in the base model (see figure 4.2). Now all patterns in this list are successively evaluated. Once one pattern

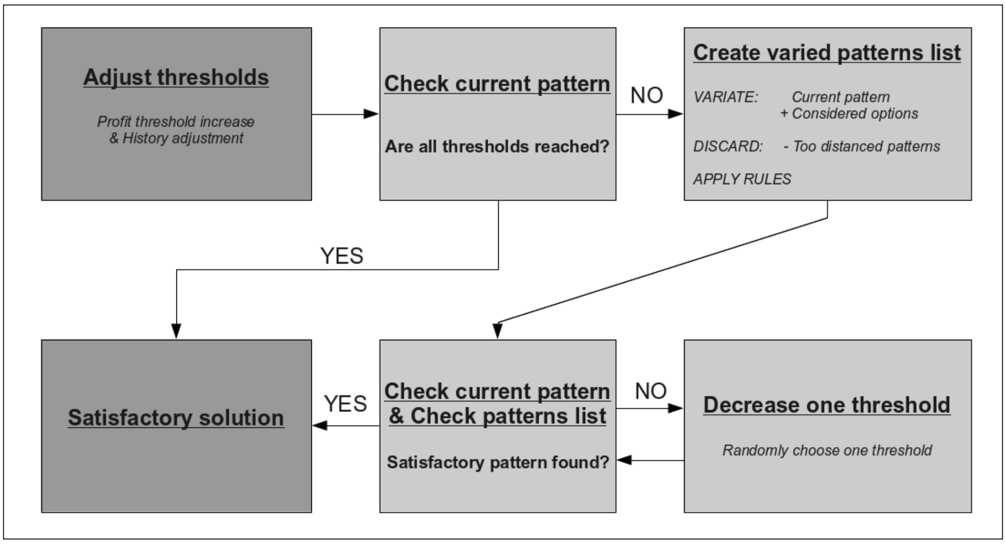

Figure 4.3: Decision making process of the satisficing model.

is evaluated as satisfactory (all thresholds are reached) this pattern is chosen and the decision making process ends. Note that the order of the patterns in the patterns list is randomised.

If all patterns in the "varied patterns list" are not satisfactory one threshold is randomly chosen and decreased. Again first the current pattern and then all patterns of the "varied pattern list" are successively evaluated and if one pattern is evaluated "satisfactory" it is chosen. This procedure is repeated until a solution is found.

5 Simulation results

This section contains several simulation results of the satisficing model described in the last chapter. First some general findings concerning parameter values and the diffusion process are investigated. Then results for standard parameter values and the effect of differing random number sequences is shown. Later the influence of the new parameters ω, μ and δ is presented. Since the parameter space is vast and time and computer resources are limited, no Monte-Carlo analysis has been executed. In contrast parameter variations were executed one after another, whereas five different values per parameter were simulated.

All following simulations contain the same options and policy changes. Initial land-use pattern are set in the same way as in the base model (see Holtz (2009, p.58 ff)). Initial thresholds are in most cases set to the same value as the outputs of the initial land-use pattern[1]. Each run reported represents an average of ten runs with the same parameter values but differing random number sequences.

As stated in chapter 4 three new parameters (δ, μ, ω) appear within the satisficing version. Additionally to those the following parameters were carried over from the utility-maximizing model (see Holtz (2009, p.25)):

- *Family labour* represents how much labour force is available on the farm without hiring new workers
- κ, a representation of the maximum labour force to which the farm is extendable
- α_s relates to land-use patterns' distance in terms of farmers' knowledge and skills
- α_c relates to land-use patterns' distance in terms of sunk cost and necessary investments

5.1 Diffusion process

At first the diffusion process with standard parameter values is investigated. For the specific parameters of the satisficing model the following values are assumed: $\delta = 0,1,\ \mu = 0,25,\ \omega = 0,05$. Figure 5.1 shows the area of irrigated garlic, irrigated melons and the amount of water extracted for the parameters described above and all other parameters as in the base model (see: Holtz (2009, p. 30)). Garlic and melons represent an example

[1] This is not always the case, as initial threshold are set at least to 0,1. Such a minimum is necessary as some initial land-use pattern return an output of 0 on a specific scale (e.g. if the land-use pattern exceeds the farmer's maximum labour load). However thresholds have to be greater than 0 in this model.

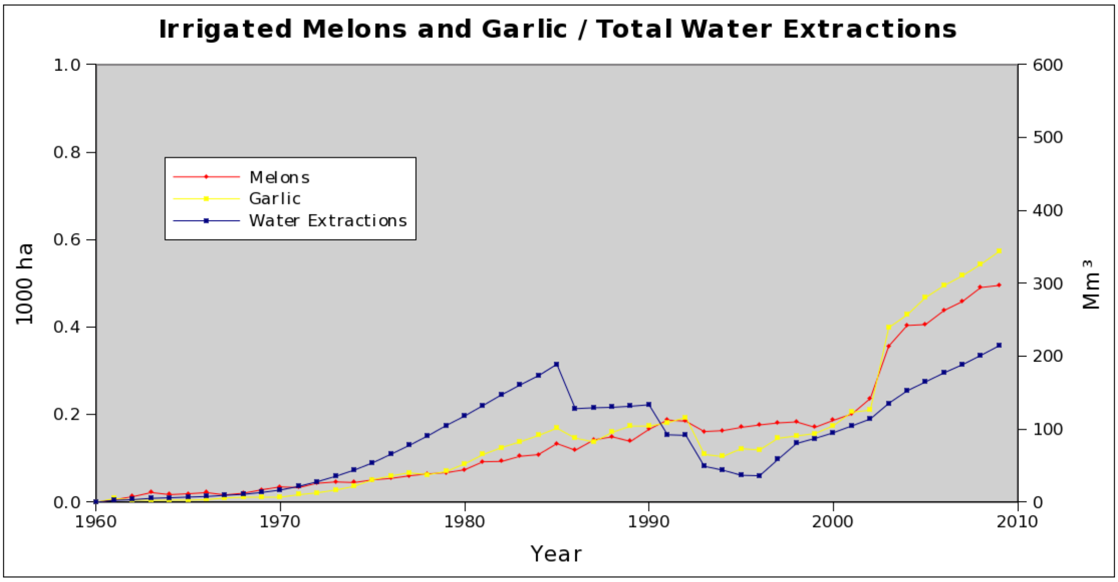

Figure 5.1: Irrigated area and water extractions for $\delta = 0,1$; $\mu = 0,25$; $\omega = 0,05$. All other parameters are set as in the base model (Holtz, 2009, p. 30).

for more profitable crops, that have to be irrigated and follow a diffusion process in this model. Irrigation technologies are unknown to farmers at the beginning of the simulation, they appear as diffusing innovations (see chapter 4) as well. Figure 5.1 shows that the diffusion process is very slow with parameters as stated above. By 1985 the amount of extracted water in this model is only at 30% of what is empirical observed and throughout the whole simulation extractions are at a sustainable level. Irrigated horticultural crops as garlic and melons are almost not existent. Empirical data show, that around 18.000 ha of irrigated melons exist in the MOA by 1990, whereas this value does not exceed 500 ha (2,8% of empirical observations) by the end of this simulation.

Given these results, it is doubtful, if simply carrying over parameters from the base model produces any meaningful results. As agents don't optimize in this model, it seems plausible that innovations are considered at a later time compared to agents who rethink their decisions every year and choose the 'best' alternative. Thus it makes sense to lower the parameters, which delay the diffusion process. In this model such parameters are α_s and α_c. Those parameters do not base on any real-world data, therefore they can be varied in order to create more realistic results concerning the diffusion process. In all following simulations α_s and α_c are reduced by 80%.

5.2 Results for standard parameter values

Considering the findings above, a standard parameter set has been developed, that constitutes a base for following simulations (see table 5.1). While *Family labour*, κ, α_s

and α_c are specified for different farm types, the new parameters μ, δ and ω are equal for all farm types. Values for *Family labour* and κ are equal to the base model.

	Family Labour	κ	α_s	α_c	μ	δ	ω
Business Farm	0.4	5.0	4.0	4.0			
Family Farm	1.0	2.0	6.0	6.0	0.25	0.1	0.05
Part-time Farm	0.4	0.6	10.0	4.0			

Table 5.1: Standard parameter set for all farm types.

Figure 5.2 shows results for simulations with standard parameters as in table 5.1. A transition from rainfed to irrigated agriculture is observable. Main irrigated crops are vineyards, traditional cereals and high yield cereals. At the end of the simulation irrigated horticultural crops and sugar-beet play a more significant role.

Irrigated traditional and high yield cereals increase strongly up to 1985. By the year 1993 irrigation of such crops has dropped to the level of 1970 as a response to different formal rules ('water act', AEP). From then on no significant increase in irrigation of traditional and high yield cereals is observable. Model dynamics regarding irrigated vineyards are different. After dropping in the mid- 1980's, this area increases massively after 1997, when the 'vine law' goes out of force. The area of irrigated horticultural crops and sugar-beet consistently increases in this model. Since horticultural crops and sugar-beet are unknown to farmers at the beginning of the simulation, these crops follow a diffusion process. Although over the years horticultural crops and sugar-beet play a more significant role, the diffusion process hasn't finished by the end of the simulation.

The effect of differing random number sequences can be seen in the small figures of figure 5.2. For irrigated vineyards and irrigated COP (traditional cereals, high yield cereals, sunflower) almost no difference between simulations with differing random number sequences is observable. Regarding crops that follow a diffusion process, like horticultural crops (melons, garlic, paprika) or sugar-beet, quantitative differences between simulations with differing random sequences are observable. After ten runs values for irrigated horticultural crops at the end of the simulation vary between 12.000 ha and 16.200 ha.

However, this model does not aim at reproducing data quantitatively as empirical data is uncertain and scarce anyway. Regarding the qualitative dynamics no considerable effects of differing random number sequences are observable. Outlying curves (as observed for irrigated sugar-beet) do not reflect differing qualitative behaviour. It can be concluded that differing random number sequences have no considerable effect on the qualitative results of this model. As stated above, all following simulations represent an average of ten runs.

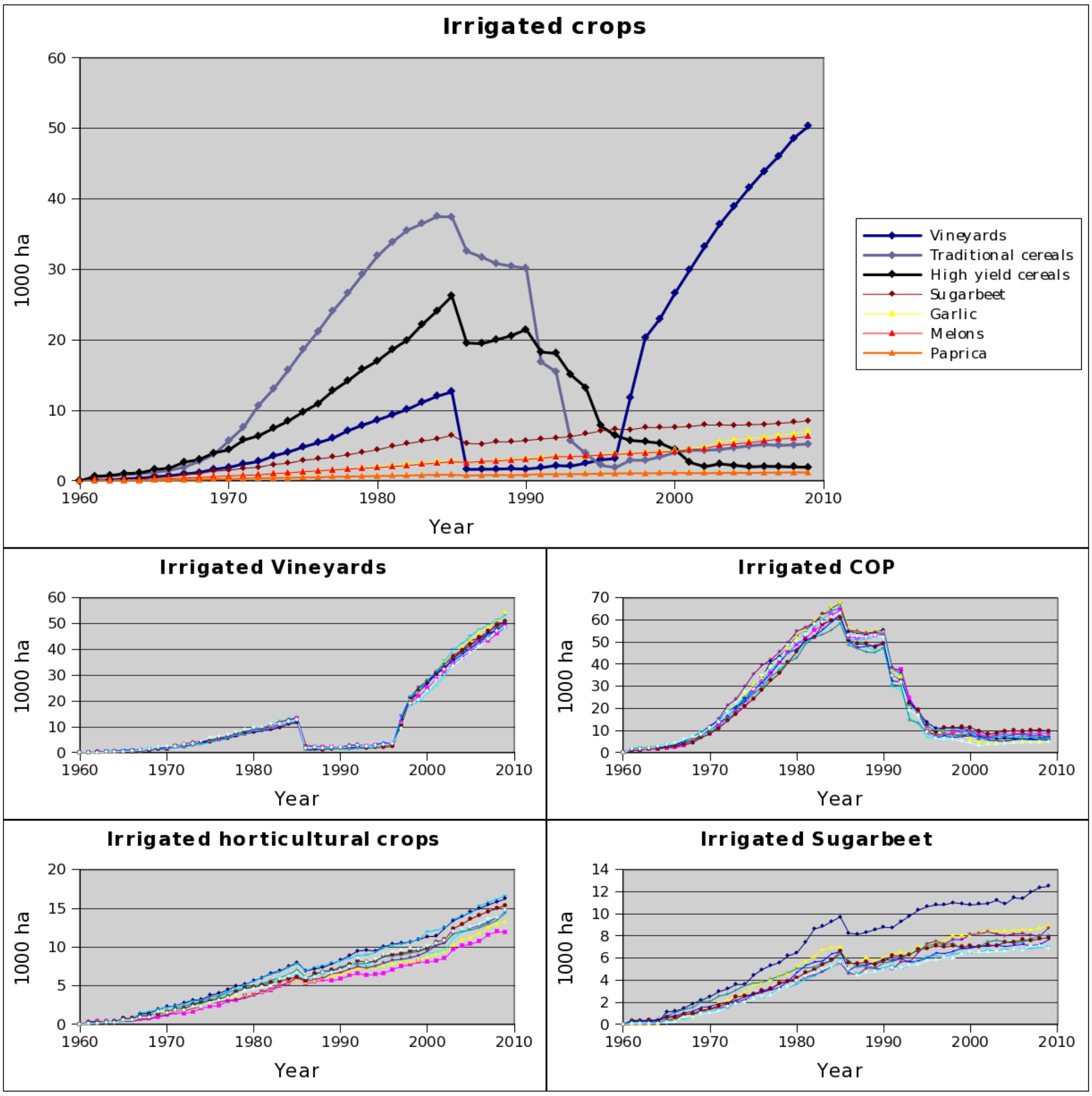

Figure 5.2: The above figure shows irrigated crops for standard parameter values as in table 5.1. The small figures show ten runs with identical parameters but differing random number sequences; from left to right and up to down irrigated vineyards, irrigated COP (traditional cereals, high yield cereals, sunflower), irrigated horticultural crops (garlic, melons, paprika) and irrigated sugar-beet.

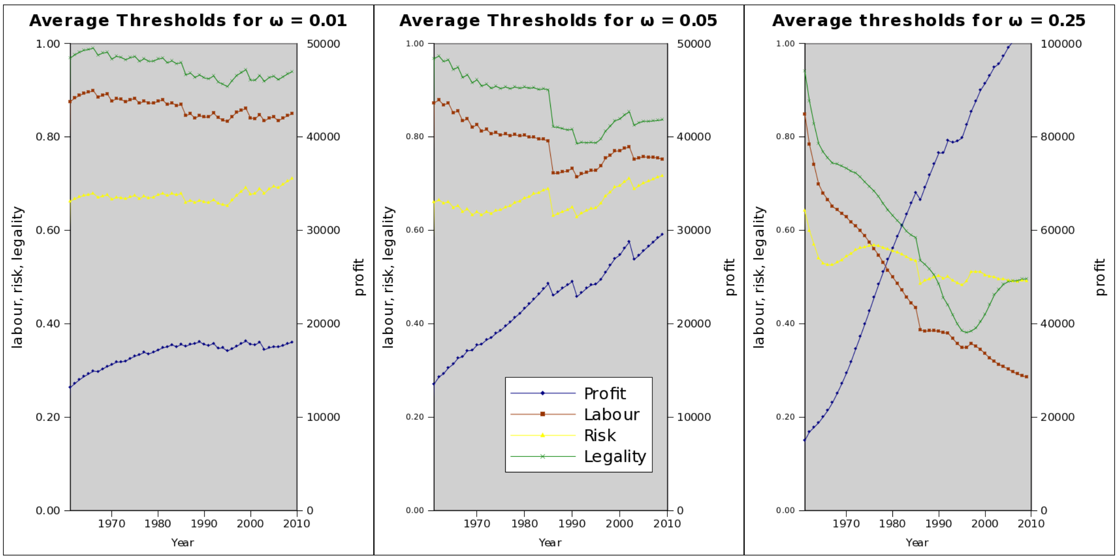

Figure 5.3: Average thresholds of all farmers with different values for ω (all other parameters as in table 5.1). Figures show from left to right average thresholds for $\omega = 0.01$, $\omega = 0.05$, $\omega = 0.25$.

5.3 Variation of ω

ω defines the amount of the yearly profit threshold increase. In figure 5.3 the effect of different values for ω on the average thresholds of all farmers is displayed. The higher ω the greater the average profit threshold compared to all other thresholds.

Figure 5.4 shows the effect of different values for ω on water extractions and on the area of irrigated crops. In general increasing ω has two effects: a shift from non-irrigated crops to irrigated crops and a shift from non-horticultural crops to horticultural crops. Therefore high ω lead to more irrigation overall (in particular of horticultural crops) and hence to a higher amount of water extractions.

Up to the year 2000 different ω have a considerable effect on irrigation of COP, generally higher ω lead to more irrigation of those crops. For very high ω there is a strong shift from irrigated COP to irrigated horticultural crops and thus between the mid-1970's and the mid-1990's results show a lower value of irrigated COP for $\omega = 0.25$ than for $\omega = 0.1$. The same effect can be found for sugar-beet. However, parameter values such as $\omega = 0.25$ have to be interpreted carefully, as this would mean farmers expected a yearly increase in their profit of 25%. After 2000 irrigation of COP seems to be hardly effected by different ω, in any scenario values for irrigated COP stay moderate below 10.000 ha.

The effects mentioned above are comprehensible when considering figure 5.3. Scenarios with high ω result in higher average profit thresholds and thus profit plays a more important role in the decision making process. This leads to an increase in irrigations and to a shift towards more profitable crops.

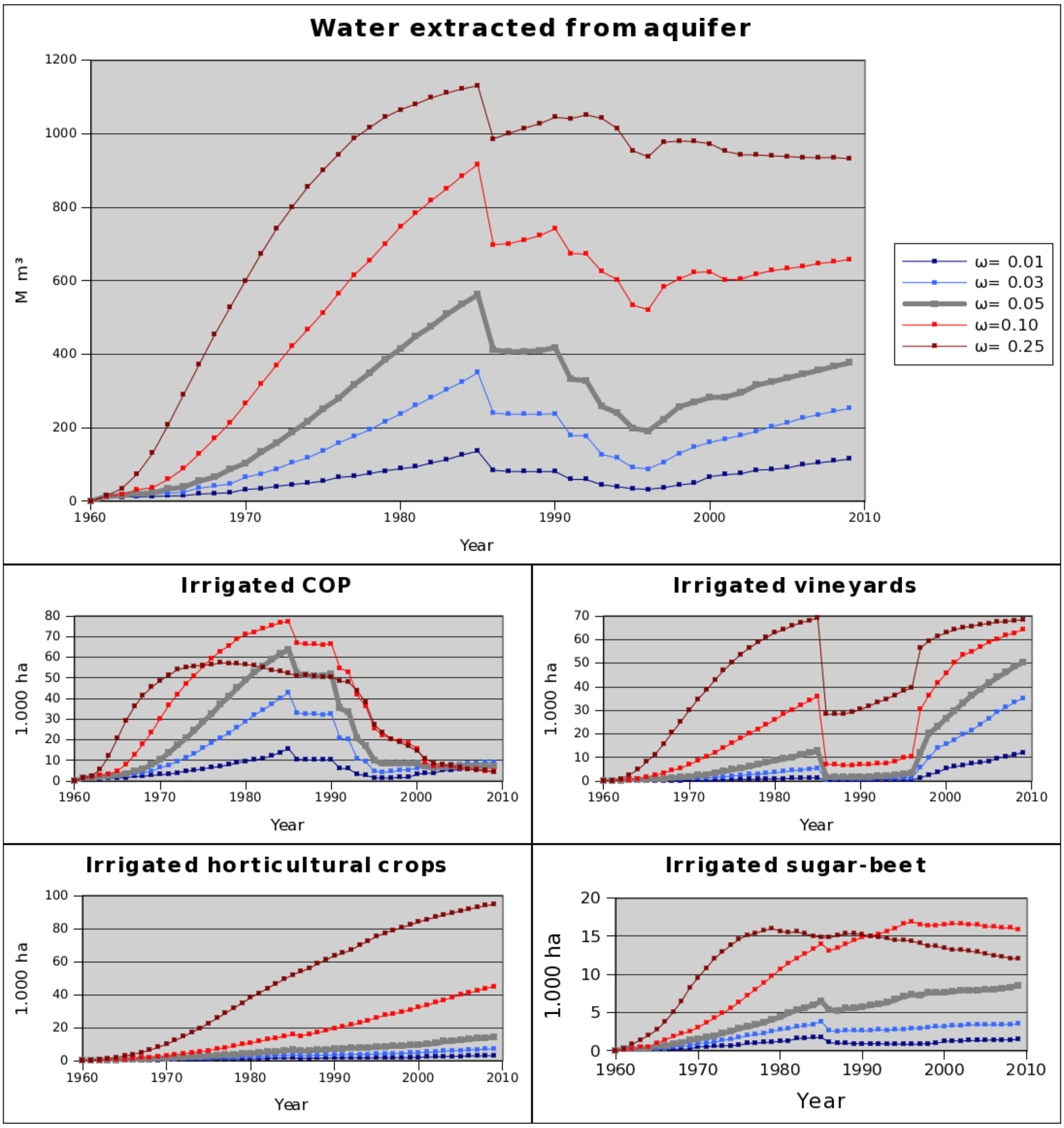

Figure 5.4: The above figure shows water extractions with different values for ω (all other parameters as in table 5.1). The small figures show irrigated COP (traditional cereals, high yield cereals, sunflower), irrigated vineyards, irrigated horticultural crops (garlic, melons, paprika) and irrigated sugar-beet with the same parameter values.

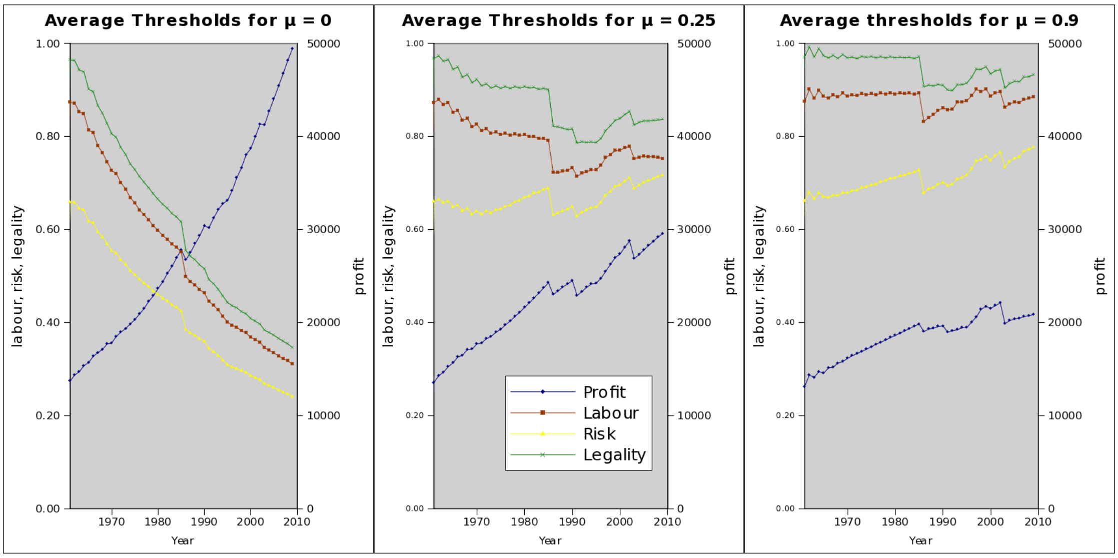

Figure 5.5: Average thresholds of all farmers with different values for μ (all other parameters as in table 5.1). Figures show from left to right average thresholds for $\mu = 0$, $\mu = 0.25$, $\mu = 0.90$.

5.4 Variation of μ

μ defines the amount of the history adjustment of thresholds. In figure 5.5 the effect of different values for μ on the average thresholds is displayed. For $\mu = 0$ no history adjustment of thresholds takes place. In this case the only increasing threshold is the profit threshold. Throughout the simulation, the profit threshold increases and the average of the other thresholds drops constantly. Thresholds are influenced by past outcomes for $\mu > 0$. $\mu = 0.25$ lead to a doubling of the average profit threshold throughout the simulation, while the other thresholds vary between 0.7 and 0.9 by the end of the simulation. For very high μ (e.g. $\mu = 0.9$) the influence of ω decreases (see equation 4.4) and the profit threshold stays comparatively low.

Figure 5.6 shows the effect of μ on water extractions and on irrigation of different crops. For low μ similar findings can be noted as for high ω: a shift from non-irrigated to irrigated crops and from non horticultural crops to horticultural crops. However, these effects are less strong for $\mu = 0$ than for $\omega = 0.25$. μ has no considerable effect on the value of irrigated COP at the end of the simulation. For $\mu = 0$ or $\mu = 0.1$ irrigated COP is partly replaced by horticultural crops and therefore between 1975 and 1990 irrigation of COP is lower than for $\mu = 0.25$.

Again the parameter μ displays the importance of profit in the decision-making process. For low μ a stronger increase of the profit threshold compared to the other thresholds is observable. History adjustment is stronger for high μ, the importance of labour, legality and risk increases in such scenarios. Since irrigation includes more labour-needs and may lead to illegal behaviour, the shift towards irrigation is weaker in such scenarios.

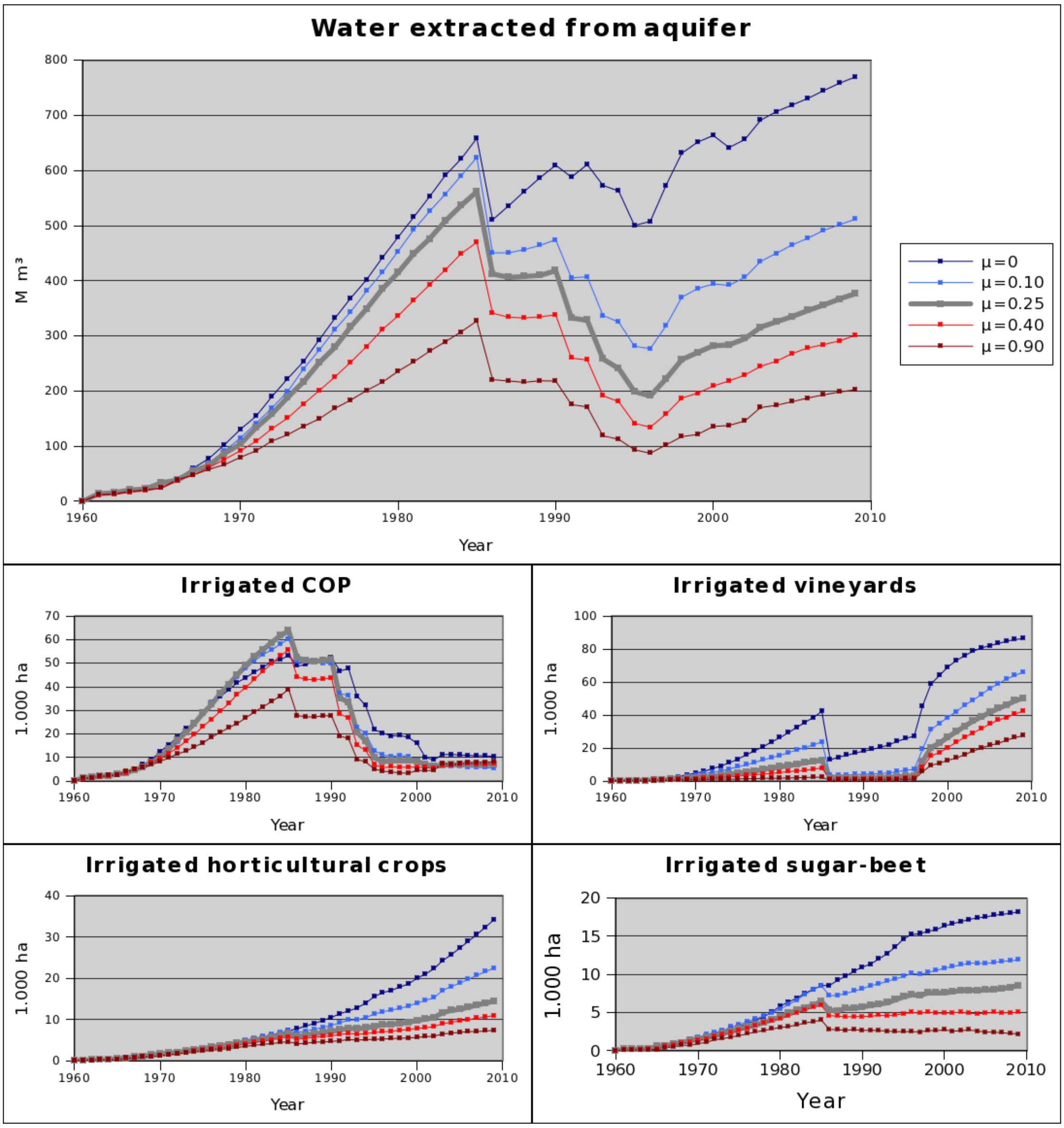

Figure 5.6: The above figure shows water extractions with different values for μ (all other parameters as in table 5.1). The small figures show irrigated COP (traditional cereals, high yield cereals, sunflower), irrigated vineyards, irrigated horticultural crops (garlic, melons, paprika) and irrigated sugar-beet with the same parameter values.

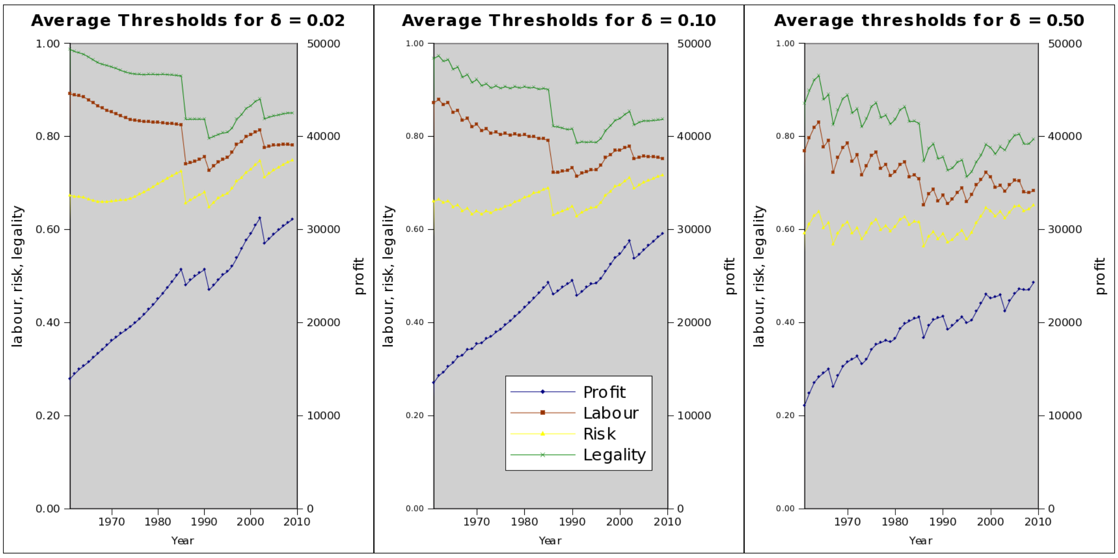

Figure 5.7: .
Average thresholds of all farmers with different values for δ (all other parameters as in table 5.1). Figures show from left to right average thresholds for $\delta = 0.02$, $\delta = 0.10$, $\delta = 0.50$.

5.5 Variation of δ

If farmers don't find a satisfactory land-use pattern in their 'varied patterns list', one randomly chosen threshold is decreased (see chapter 4). The amount of this decrease is defined by δ. A lowering of δ has almost no quantitative effect on the thresholds (see figure 5.7). The curves for the thresholds run more smoothly with $\delta = 0.02$ but the values for average thresholds are almost identical to the standard scenario of $\delta = 0.10$. When δ gets high, threshold curves seem to be more fluctuating and average thresholds are little lower, in particular the profit threshold.

The effect of varying δ on water extractions and on irrigation of the different crops can be seen in figure 5.8. One can state, that δ has no strong effect on model results. Very high δ seem to retard the diffusion process of irrigation technologies and therefore between 1970 and 1990 high δ lead to less water extractions. However, water extractions are almost equal in all scenarios at the end of the simulation.

There is little effect of different δ on irrigation of the different crops. Most crops get more irrigated for low δ up to 1990. After 1990 low δ lead to less irrigation of COP, whereas irrigation of the other crops increases. However, as stated above this effect is not strong and does neither change qualitative nor quantitative results in a significant amount.

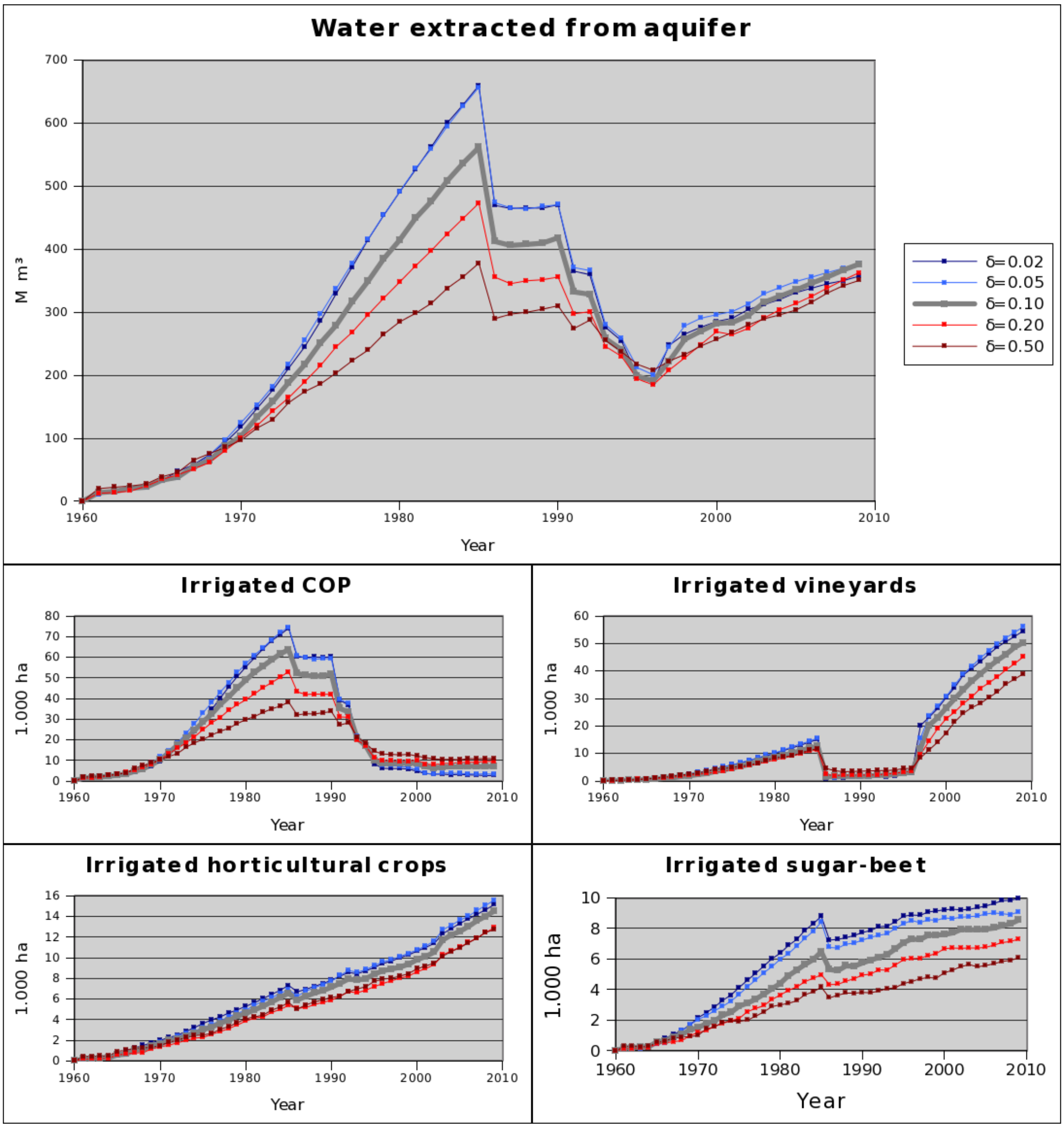

Figure 5.8: The above figure shows water extractions with different values for δ (all other parameters as in table 5.1). The small figures show irrigated COP (traditional cereals, high yield cereals, sunflower), irrigated vineyards, irrigated horticultural crops (garlic, melons, paprika) and irrigated sugar-beet with the same parameter values.

6 Discussion

6.1 Model design

As this model includes a time span of 50 years and represents significant external changes within that time (e.g. new appearing irrigation technologies and changing formal rules), flexible thresholds have to be implemented. What is satisfactory for a farmer in 1960 is probably not satisfactory anymore 50 years later, particularly concerning farmers' profit.

One specific feature in the modelled decision-making process is the yearly increase of the profit threshold. As stated in chapter 4 this feature has been implemented to represent, that farmers want to be part of the growing economic wealth in Spain and in the 'Mancha Occidental Aquifer' (MOA). Technically the yearly profit threshold increase plays an important role for model dynamics. If this feature is not implemented, farmers will not change their decisions unless some external factors (law- or price changes) worsen their current situation. In principle the model results would remain constant over time. However, in the MOA we can observe changing land-uses on a big scale (see figure 2.2), thus flexible threshold and increasing profit thresholds are essential for this model.

Simon's concept is yet little used by those researching agricultural innovation (Gotts et al., 2003). Gotts et al. (2003) implemented satisficing in an agent-based social simulation model of land use change. However their work differs very much from this work since the underlying farming models differ in some essential aspects. In Gott's model land use pattern only vary in their economic return. Consequently aspiration levels of farmer are unidimensional. Additionally, the model includes a stochastic variability of each years land use patterns' economic return (relating to varying external conditions, such as weather conditions or prices). This means, farmers' output can go below their thresholds because of "having a bad year". In that case constant thresholds in a satisficing model with repeated decisions can still produce dynamically changing results. However, stochastic variability of land-use patterns' economic return is not explicitly considered in the model used for this work and therefore constant thresholds do not work here.

One specific characteristic of the satisficing concept is, that it is a non-compensatory strategy, which means that a good feature of an option can not compensate negative attributes. If a land-use pattern is for example evaluated as being extremely risky, other attributes as very high profits can not compensate this, the option will not be chosen. Thus satisficing favours "all-round options", which don't contain a negative outlier. Paprika for example plays hardly any role in this model, a plausible reason is its massive required labour needs (see Holtz (2009, p. 49)). Anyway using a non-compensatory strategy is arguable. It seems for example plausible, that farmers require a minimum value of profit and that land-use pattern, that return less profit than such a minimum can not compensate this by a high legality value. On the other hand, it is doubtful that land-use patterns, which would lead to a violation of laws to a large extend are not chosen at all despite low labour needs and high potential profits. This point leads to another debatable feature in the satisficing model: the fact, that the scales profit, labour, risk and legality are equally weighted. This aspect will be discussed in section 6.3.

6.2 Comparing model results with empirical data

When comparing model results with empirical data, it should be noted that empirical data is scarce (see chapter 2) and that calibration of parameters is based on these available data. Thus, validation of the model by comparing results to empirical findings is only possible to a limited extent.

In the model the amount of extracted water is similar to empirical observations (compare e.g. figure 5.4 for $\omega = 0.05$ with figure 2.1). Both, empirical observations and simulation results, show extractions just before 1990 of about 600 Mm^3. Thereafter the level drops down to 200 Mm^3 and increases again up to 400 Mm^3.

Available data on irrigated crops in the MOA from 1974 to 2003 is presented in figure 2.2. Results of simulations with the standard parameter set (figure 5.2) show mainly three irrigated types of crops: vineyards, traditional cereals and high yield cereals. Those crops belong to the most irrigated ones empirically observed as well. At the end of the simulation irrigated horticultural crops and sugar-beet play a more significant role. This finding is not supported by empirical data. Though irrigated melons increase up to 1990, they only play a minor role after that time .

In this model the water act (1985) creates a first cut in formerly increasing irrigations. Especially irrigation of vineyards disappears almost completely. This result is explainable by the findings above about negative outliers. As the 'vine law' is still in force at 1985, farmers are not allowed to irrigate vine. All of those who did irrigate vineyards before could not claim any pumping quotas for this area and thus irrigation of vine led to a violation of both laws (water act, vine law) to a large extend. Therefore the legality value of such land-use pattern is very low. As stated above the satisficing concept penalizes negative outliers to a large extend, which is the reason why in this model irrigated vine plays hardly any role between 1986 and 1997. Due to scarce data the real influence of the water act is vague, but it is assumed that many farmers did not respect restrictions on water extractions (Llamas and Martinez-Santos, 2005). Thus the effect of the water act is estimated to be less strong in reality than in this model.

The Agro Environmental Programme (AEP) had a considerable influence on irrigation in the MOA (Varela-Ortega, 2007). Many farmers joined the programme and voluntarily reduced water use. A drop in irrigation of all crop types is empirically observable. In this model, the AEP leads to reduction of irrigations as well. Simulations show a drop of irrigation for all different crops, each of them drops down to less than 10.000 ha by 1995. Especially the drop of irrigation of traditional cereals is remarkable. Empirical data show, that irrigation of vineyards and traditional cereals haven't dropped to such an extent. Also these data show a peak of sunflower around 1993. This model is not able to reproduce this feature, sunflower hardly plays any role at all in all simulations. However, the effect of the AEP, price drops of COP and compensatory payments (CAP), that happened at the same time, cannot be clearly separated.

In 1997 the 'vine law' goes out of force, which greatly changes the situation in this model. The main drawback for irrigation of vineyards before was its low legality value. Now irrigation of vineyards is legal and the legality value increases for such land-use pattern. The effect on simulation results is immense, within 12 years the area of irrigated vineyards increases to 50.000 ha, while irrigation of most other crops stays comparatively low. However, this finding is detached from reality. Though empirical data show an increase of irrigated vineyards in the mid-1990's, this happens before the 'vine law' goes out of force. After 1995 the value for irrigated vineyards remains relatively constant between 40.000 and 50.000 ha.

Another feature plays a more prominent role when looking at empirical data: around 2003 irrigation of traditional cereals has increased massively up to 60.000 ha. This model is not able to capture this feature at all. All simulations with any of the presented parameter combinations show moderate irrigation of traditional cereals after 1995.

When looking at the underlying data for the time after 1997 (Holtz, 2009, p. 49ff), such a result is not surprising. In the following two hypothetical land-use patterns will be compared:

(a) The whole farm is cultivated with irrigated traditional cereals.

(b) Two thirds of the farm are left fallow, one third of the farm is cultivated with irrigated vineyards.

The following results hold for almost all farm sizes[1]:

- Land-use pattern (b) returns more profit[2] than land-use pattern (a).
- Risk of land-use pattern (b) is lower than for land-use pattern (a).
- Labour needs for land-use pattern (b) are lower than for land-use pattern (a).
- The legality value of both scenarios is approximately on the same level.

Concerning the legality value, it is the case that from 1997 onwards irrigation of vineyards is not forbidden. The amount of water needed per ha of irrigated vineyards is comparatively low. Additionally the irrigation technology 'drip irrigation' can be applied on vineyards and not on traditional cereals. This technology is more widespread by the end of the simulation and it is the most water-efficient one. Thus average water needs

[1]Some findings do not hold for big farms (150 ha) anymore, since labour needs per ha irrigated vineyards are approximately four times higher than for irrigated traditional cereals. This effect is not very strong, since big farmers are always business farmer and their maximum labour force to which the farm is extendable is comparatively high. Thus more labour needs only lower the labour threshold in a moderate extent. However, the area of big farms is less than 20% of total area.

[2]Possible compensatory payments by the CAP are included for both scenarios.

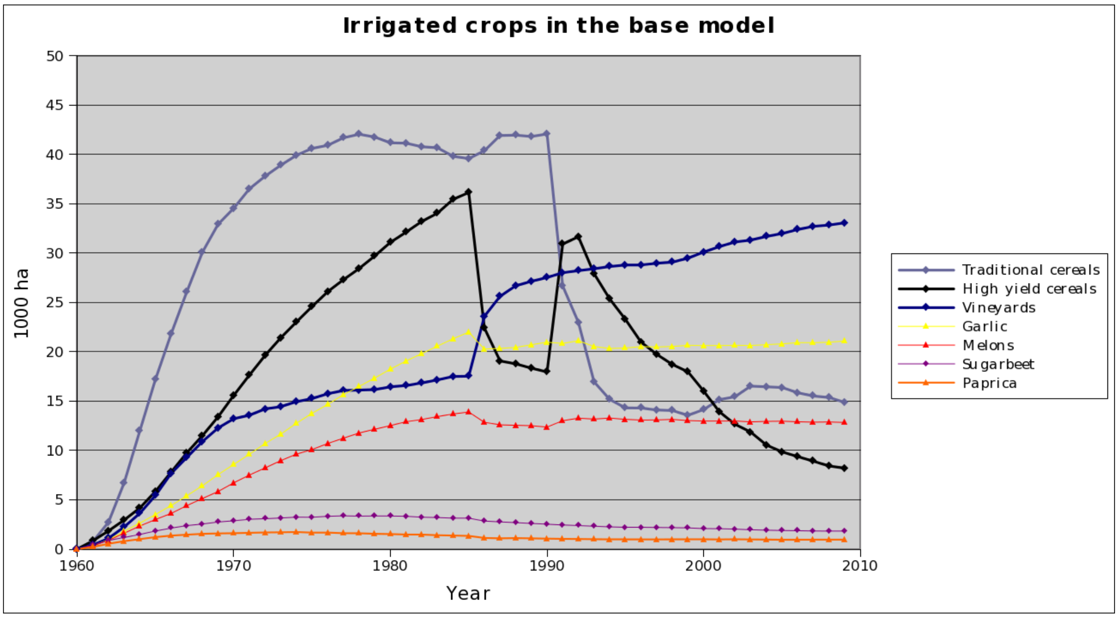

Figure 6.1: Area of irrigated crops in the base model (parameters see Holtz (2009, p.30)).

are lower for irrigation of vineyards than for irrigated traditional cereals. If additionally a part of the farm is left fallow, legality values of both scenarios are approximately on the same level, even though only a reduced amount of water is granted for irrigated vineyards.

This example showed, that irrigation of vineyards on a specific part of the farm is superior or equal on all scales to irrigation of traditional cereals. Given those data, there is little reason for farmers to irrigate traditional cereals, as long as they consider irrigated vineyards as well. Sooner or later irrigated vineyards (or other cereals) catch on compared to traditional cereals. Thus it remains questionable if a differing parameter set or differing assumptions in the decision-making process could produce a strong increase of irrigated traditional cereals after 1997 as empirically observed. Moreover it seems possible, that essential data is missing or wrong in this model. Hence more emphasis has to be put on understanding, what has led to this increase of traditional cereals in reality.

6.3 Comparing model results with results of the base model

In the base model, a utility function is implemented, farmers are optimizing rather than satisficing. This leads to a speed up of the diffusion process as pointed out in chapter 5. Thus, parameters that slowed down the diffusion process are lowered in the satisficing model. Nevertheless the diffusion of new irrigation technologies is still much faster in the base model than in the satisficing version (see figure 6.1).

Concerning irrigated crops it is notable, that in the base model irrigation of garlic is significantly higher, as it returns higher profits and therefore compensates for high labour loads and for an illegal amount of necessary groundwater extractions. However, the satisficing concept is non-compensatory. Hence there is less irrigated garlic in the satisficing model not only due to a slower diffusion process but also to the fact, that irrigated garlic includes high labour loads and illegal behaviour.

Results of the base model are more sensitive to data variations. This becomes apparent when comparing results for melons and garlic. Both of those crops are horticultural crops with similar characteristics: returning high profits, but requiring high labour loads and having high water needs (resulting in illegal behaviour). The data used for this model somehow favours irrigated garlics especially for small farmers due to little higher profits and less risks. This advantage by a narrow margin has strong effects in the base model: the area of irrigated garlic is almost twice as high as for irrigated melons. In the satisficing model values for irrigated garlic and irrigated melons are almost equal throughout the simulation. When farmers don't optimize most of them will be indifferent between options, that contain almost equal characteristics (such as melons and garlic).

The effects of different laws and programmes differ between the two models. In the base model the water act leads partly to a substitution of irrigated vineyards for irrigated high yield cereals or horticultural crops. In contrast irrigated vineyards almost disappear in the satisficing model at this point. As a response to the AEP, to new pumping quotas, to lowering prices for COP and to the CAP, traditional and high yield cereals drop down in the base model. However, this decrease is less strong than in the satisficing model. When the vine law goes out of force no strong effects can be seen in the base model, while this has immense effects for the satisficing model (see chapter 5).

In both models the four scales profit, labour, risk and legality are taken into account when evaluating potential land-use patterns. One main difference between the two models is, that those scales are evaluated heterogeneously in the base model, while they are overall evaluated homogeneously in the satisficing model. In the base model four additional parameters define the impact of profit, risk, legality and labour for each farm type in the decision-making process. In contrast, the satisficing model evaluates all scales equally: a chosen land-use pattern must exceed all thresholds. That's why being legal or at least "being not too illegal" plays a much more important role in the satisficing model than in the base model. This feature is one explanation of differing reactions on changing laws.

Many authors point out that profit is of major relevance for farmer decision-making (e.g. Lopez-Gunn (2003); Edwards-Jones (2006)). This has been partly represented in the satisficing model, a constant increase of the profit threshold is implemented. The other three thresholds do not increase independently of history, their importance in the decision-making process is equal. Even though the satisficing model hence requires less parameters, it remains debatable if the resulting loss of heterogeneity leads to implausible assumptions.

Another characteristic of the satisficing model is an increasing importance of profit over the years. This is due to the specific design of this model and results in constantly

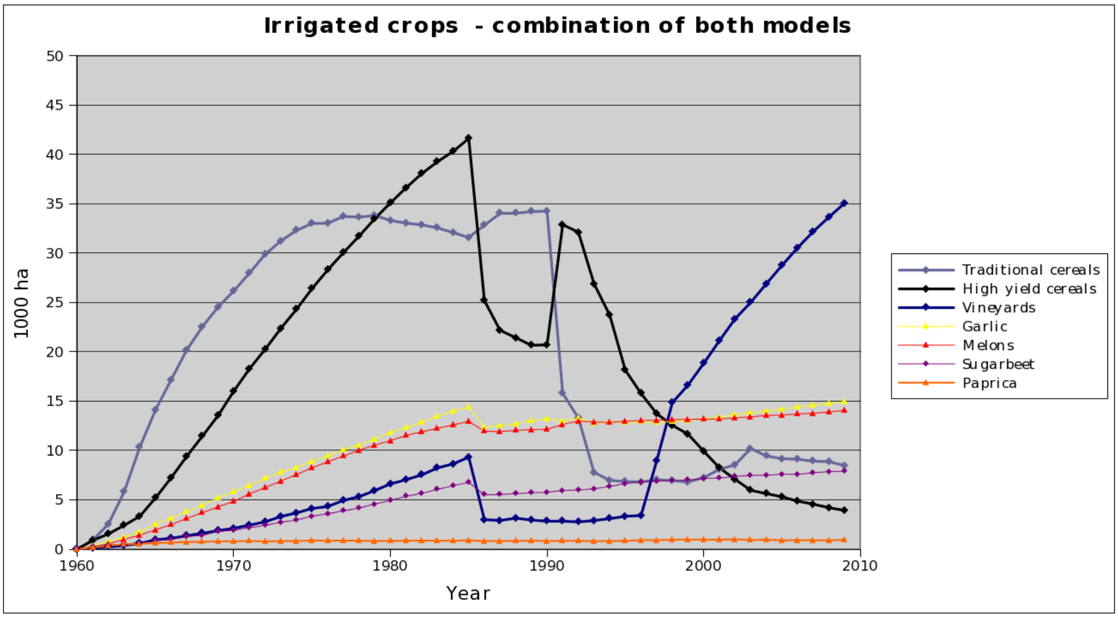

Figure 6.2: Area of irrigated crops for a combination of the base model and the satisficing model. The base model has been applied for business farms (parameters see Holtz (2009, p.30)) and the satisficing model for family farms and part-time farms (parameters as in table 5.1).

increasing irrigation of horticultural crops. This feature can not be observed in the base model, the importance of the different scales is heterogeneous but constant over time.

6.4 Combination of both models

A combination of both models has been computed. For business farmers the base model with a utility function and optimizing agents was applied. Family farmers' and part-time farmers' decisions are represented by the satisficing model. Results on irrigated crops can be seen in figure 6.2. They show a mixture of characteristics of both models. Horticultural crops play a much more important role now, compared to empirical data they are overrated. Responses to laws are partly different. The role of legality is reduced in the utility model, thus the effects of laws are smaller. New pumping quotas lead to an increase of irrigated high yield cereals for a short time, this effect can be observed in the base model as well. After the vine law goes out of force, the area of irrigated vineyards still increases, but not to such a large extend as in the satisficing model.

However, a combination of both models is still not able to capture the empirically observed increase in irrigated traditional cereals after 1997. The use of horticultural crops is still overrated (as in the base model). Irrigation of vineyards still depends to a great extent on the vine law. A combination of the two models hence doesn't produce any more or less meaningful results than one of the models by itself.

7 Conclusions

In this work satisficing was implemented in an agent-based farming model dealing with groundwater over-exploitation in the "Upper Guadiana Basin" [1].

Main findings are, that the implementation of satisficing as a model for farmers' decision-making has considerable influences on model results. Model dynamics differ compared to a utility-maximizing model, particularly concerning the diffusion process of innovations and responses to laws and policies.

Furthermore this work presents one feasible way of implementing satisficing in an agent-based model with repeated decisions, including changing context conditions, such as the availability of irrigation technologies or changing policies. It is shown, that a number of assumptions and rules have to be implemented in order to transform the theoretical concept of satisficing into a usable model to represent decision-making in an agent-based model (see chapter 5). It is expected, that the specific formalisation of those rules influence simulation results to a much larger extent than changing parameters. In order to study those effects, more emphasis has to be put on finding ways to transform the concept of satisficing into a feasible decision model in agent-based models.

There are several aspects, in which the satisficing approach appears to be more realistic concerning decision-making of farmers (see chapter 3). However, this model is not more able to reproduce empirical results concerning land-use change than the base model, which uses the concept of utility-maximization (see chapter 5). In particular the empirically observed increase of irrigated traditional cereals after the mid 1990's is neither explainable nor reproducible with this model.

Obviously this implementation of the satisficing concept is still far away from representing real-world decision-making. One explanation could be that assumptions in the decision-making process are wrong. Moreover there could be essential features, that are not included in this model (e.g. tradition-based farming decisions). Given the uncertainties regarding data and the findings in section 6.2, it remains still possible, that wrong data (in the model or in empirical observations) is a reason for the inconsistency of model results and empirical observations regarding irrigated traditional cereals after 1997. In order to increase understanding of farmers' decision-making, it is thus essential to find out about reasons, that have led to this phenomena in reality.

All in all this work helps to understand barriers and potential effects of using satisficing as a decision-making model in agent-based models. Moreover this work raises questions related to our understanding of real-world decisions concerning land-use change in particular in the 'Mancha Occidental Aquifer'. This work hence delivers impulses for future works on those topics.

[1] The code of this model is available on request. Please contact Marvin Nebel (marvinnebel@gmx.de) or Georg Holtz (Georg.Holtz@usf.uos.de).

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Erklärung

Hiermit versichere ich, dass ich die vorliegende Arbeit selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe, dass alle Stellen der Arbeit, die wörtlich oder sinngemäßaus anderen Quellen übernommen wurden, als solche kenntlich gemacht sind und dass die Arbeit in gleicher oder ähnlicher Form noch keiner Prüfungsbehörde vorgelegt wurde.

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