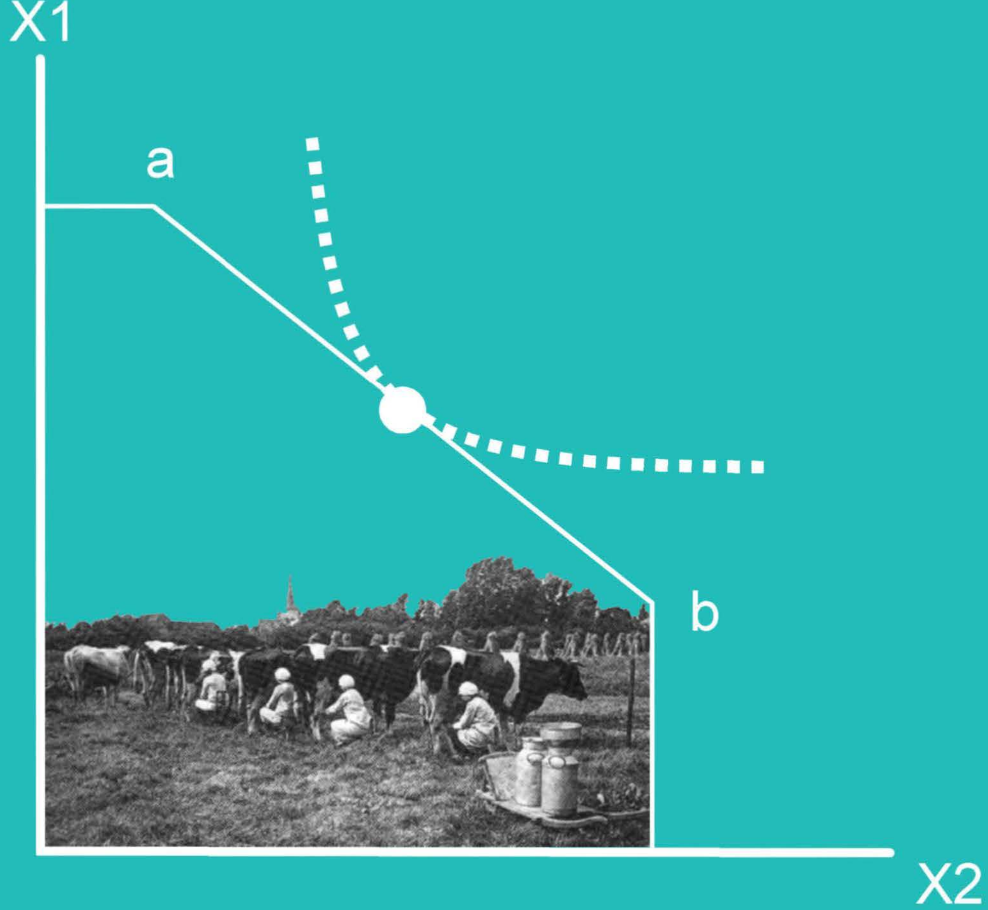
Farm-level mathematical programming tools for agricultural policy support

Jeroen Buysse



UNIVERSITEIT GENT

FACULTEIT BIO-INGENIEURSWETENSCHAPPEN

“All models are wrong, but some are useful.” (Howitt, 2005)

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Farm-level mathematical programming tools for agricultural policy support

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Voorwoord / Preface

Sinds mijn eerste stapjes programmeerwerk met een rekenmachine ben ik geïnspireerd door het concept dat het samenbrengen van een aantal eenvoudige rekenregels kunnen leiden tot verbazend vernuftige systemen. Het is voor mij ook een uitdaging geworden om complexe systemen te proberen ontleden en op te delen in kleine en eenvoudige stapjes. Deze bewondering voor de eenvoud heeft me gemotiveerd tot het maken van dit doctoraat.

Ik ben Prof. Guido Van Huylenbroeck dan ook zeer dankbaar omdat hij me de kans heeft gegeven om te werken aan een bio-economisch simulatiemodel van een melkveebedrijf en later aan het SEPALE project. Er bestaat geen twijfel over het feit dat zonder deze kansen, aanmoedigingen en steun van Prof. Guido Van Huylenbroeck dit doctoraat er niet zou geweest zijn.

Bij de uitwerking van het onderzoek heb ik gelukkig ook kunnen rekenen op de hulp van de andere mensen met wie ik heb samengewerkt: de collega's in het SEPALE project, collega's van de vakgroep landbouweconomie en van Stedula.

Voor de gegevensverzameling kon ik rekenen op de goede samenwerking met Bruno Fernagut en Ludwig Lauwers en Prof. Bruno Henry de Frahan hebben een belangrijke bijdrage geleverd aan de teksten die in dit doctoraat gebruikt zijn.

De collega's van de vakgroep Landbouweconomie hebben de aangename sfeer bepaald waarin ik de afgelopen vijf jaar gewerkt heb. Zij hebben regelmatig de rol van klankbord op zich genomen, de kaft ontworpen (Ann Verspecht) en tussendoor ook voor de nodige (sportieve) ontspanning gezorgd.

Verder zou ik ook zeker de leden van de examencommissie willen bedanken voor de evaluaties en de suggesties tot verbetering van dit proefschrift.

Ouders, familie en vrienden zou ik willen bedanken voor de kansen, appreciatie en vertrouwen en omdat zij me kennis en betrokkenheid met de landbouwpraktijk hebben gegeven die zeer nuttig zijn geweest bij de theoretische uitwerking van dit doctoraat.

Tot slot zou ik nog mijn vrouw Sara willen bedanken. Zij heeft me tijdens mijn volledige universitaire studies en doctoraatsonderzoek met veel liefde ondersteund.

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General Introduction[1]

With altering internal and external conditions in the agricultural sector, arguments for and instruments of public intervention in the EU also change. In the second half of the twentieth century, the policies were mostly based on price and market policies (trade barriers, export and import subsidies) targeted at macro level. Towards the end of the century, environmental and sustainability concerns have entered the public debate. These concerns have created an increasing interest in the link between the policies and the farms and, therefore, the interaction between macro and micro level policy impact analysis is becoming increasingly important. The outcome of a policy depends on how the stakeholders react to their policy-influenced decision-making environment. As alternative policies cannot be tested in a laboratory, possible outcomes and impacts have to be simulated or analysed before, during or after the policy action (*ex ante*, *mid term* and *ex post* evaluation) using models.

It is often thought that models are limited to algebraic representations and are hard to construct or interpret. This puts up an artificial barrier to mathematical models that causes scepticism and often prevents an open discussion about them (Howitt, 2005). Nevertheless, everyone uses models to reduce the complexity of problems or decisions. Sometimes, a model is a simple weighting of past experiences to make an analysis possible and to simplify future decisions. Another type of modelling is the process of observing and analysing successful behaviour or characteristics of others in order to be able to copy it.

[1] Parts of the introduction have been published as:

Buysse, J., Van Huylenbroeck, G. and Lauwers, L. (2006). Normative, positive and econometric mathematical programming as tools for incorporation of multifunctionality in agricultural policy modelling. Agriculture, Ecosystems & Environment, in press.

Mathematical models in agricultural economics are practical extensions of non-mathematical models, such as graphical models, which are often used to describe economic theory (Howitt, 2005). Mathematical models in agricultural policy analysis provide the link between economic theory and data, on the one hand, and practical appreciations of problems and policy orientations on the other. They are imperfect abstractions, but by virtue or their logical consistency frameworks they can provide the analyst and policy maker with a valuable economic representation of the sector and a laboratory for testing ideas and policy proposals (Hazell and Norton, 1986). Mathematical models allow us to explore many more dimensions and interactions than graphical representations, but often we can usefully use simple graphical examples to clarify a mathematical problem (Howitt, 2005).

Within the group of mathematical models for agricultural policy analysis, a wide variety of models could be identified based on the model type or the operating level of the model. There are programming, econometric or equilibrium models operating at farm level, regional, national or international level. This dissertation, however, only deals with farm-level mathematical programming models. The next subsection motivates more extensively the choice of farm-level models followed by a subsection to support the focus on mathematical programming.

Why farm-level models?

As long as price and market policies (trade barriers, export and import subsidies) prevail, impact models mainly concentrate on supply and demand analysis and equilibrium estimation. In this kind of models, individual farm reactions are only implicitly, in an aggregative way, taken into account, e.g. through supply-demand equations or linked to concepts such as regional or national farms. The impact of policies depends on the farmer's reaction to new price signals that result from price policy adjustments or from direct policy intervention in production (e.g. quota). In the case of agricultural commodities policies, it could be sufficient to analyse price and quantity shifts along the aggregated supply curve.

For environmental and sustainability concerns, however, the market is failing or only virtual and no direct price signals go to the farmer. The picture becomes more complex because society demands are not translated through the market price but need to be captured by the policy makers, who try to enforce the social optimum with new policy instruments. Some of these new policy instruments still interfere with price settings (taxes and subsidies), but the subsidies are gradually being more coupled to very specific farm conditions, linked to local conditions. Regional partial equilibrium models concentrating on the supply effects seem to be promising tools for such an analysis. Nevertheless, sectoral models are usually too aggregated to include the details that form the core of the agri-environmental measures and farm-level models present an alternative (Röhm and Dabbert, 2003).

Even when the policy is organised at a supra national level, the uptake and outcomes are highly differentiated according to farm type and farm localisation. Therefore, the interaction between the farmer's decision-making and government policy-making becomes the core issue. The overall impact of such policies will depend on both the impact per unit (e.g. income effect and biodiversity increase per targeted unit) and the uptake of policies. This uptake, or effect of the incentives on farms, depends on the farm conditions and the farmer's attitude and behaviour. The more local and farm-specific the interventions are, the more the modelling of farm-level elements becomes important.

Good farm representation and farm process understanding also enhance the development of more aggregate models. A farm-level approach increases the insight in the processes and the decision making involved and a detailed understanding of the resource availability. The farm is the actual centre of decision making in agriculture and, therefore, the interpretation of results of a farm-level approach is easier than for an aggregate approach.

Another motivation for operating models at farm level is that policy makers are increasingly interested in the regional or the sector impact of alternative polices. Policy makers may in particular be interested in the impact on different types, structures and sizes of farms and its result on the structural change of a sector. So, incorporating more correctly farmers' behaviour in policy modelling becomes an important challenge.

A farm-level approach can also have a few disadvantages.

First, farm-level models can be too case-specific hampering a generalisation of the conclusions. Therefore, farm-level models may be less meaningful for policy analysis than more aggregated models. The problem of case specificity can be minimised by the choice of a good representative model, adjustment of parameters that allow for description of more than one farm or the simulation with several farms.

Second, farm-level models often suffer from the lack of interaction with the rest of the economy. If the impact of the rest of the economy is an antecedent assumption for counterfactual research, this lack of interaction is not important. In descriptive research, where the rest of the economy is part of the research question, several actions could be taken to include market interactions. One of them, also applied in this dissertation, is the use of a compilation of farm models to allow interaction between farms, which can reflect the competition between farms for limited resources. Another approach to simulation market interaction is to link the farm-level model with a more aggregated model in order to include the impact of the demand side in the results.

Third, a farm-level model can simulate a local impact, which may not be important enough for a central decision maker. One way to check whether the impact is only local, is to combine different farms in one model or to do simulations for different farm types. However, widening the area of action of a model naturally makes it more difficult to show the technologies used in each type of farm correctly. There are specialised databases (e.g. FADN: Farm Accountancy Data Network) for observations on differences in variable costs, but not all information is available there and for some aspects models still rely on expert knowledge. This expert knowledge, which is not detailed enough to capture farm heterogeneity, can introduce a possible bias and compromise the model's capacity to represent the farms in the statistical sample (Arfini, 2001). In this dissertation, several techniques are discussed to tackle the issue of farm heterogeneity.

Next subsection provides motivations to use mathematical programming for the farm-level models.

Arguments for using programming models

The main classes of mathematical models for agricultural policy analysis include econometric models, partial equilibrium models, computable general equilibrium (CGE) models and mathematical programming models (Salvatici *et al.*, 2000).

Different types of econometric models for agricultural policy analysis exist. In agricultural economics they are often used to measure the impact of specific agricultural policy instruments on farmers' production decisions and are focused on some specific tools or commodities. Many of the short run profit maximisation models are built as modifications of the model of Chambers (1988). This standard theoretical framework has been modified to account for price uncertainty and minimum prices, production quotas, tradable output quotas, land allocation and direct payments (Salvatici *et al.*, 2000). Econometric models of agricultural production offer a flexible and theoretically consistent specification of the technology. In addition, econometric methods are able to test the relevance of given constraints and parameters given an adequate data set (Howitt, 2005).

While econometric models can be applied for agricultural policy analysis, they face difficulties in sorting the relationships into sets of constant incentives and behaviour (the constant economic structure necessary for estimation) and changed policy or technology (the impacts of a policy or technology necessary to evaluation of the change) (Preckel *et al.*, 2002). On the other hand, it must be recalled that parameter/elasticity estimates from econometric models are often used as input for other simulation models, whose size and structure does not allow direct estimation of relevant parameters (as in the case of many mathematical programming and equilibrium models) (Salvatici *et al.*, 2000).

The standard trade-focused CGE model was developed in the late 1970s and early 1980s, and has become a work horse of trade policy analysis (Robinson *et al.*, 2006). The partial equilibrium methodology concentrates on a particular subsection of the economy, with all other variables being treated as exogenous to the model. Given this concentration of resources, it is usually possible to model the particular industry / commodity chosen in much greater detail than with CGE models (O'Tool and Matthews, 2002). On the other hand, general equilibrium models attempt to describe the entire economic system, capturing not only the direct impact of a policy shock on the relevant market, but also the impact on other areas of the economy and feedback effects from these to the original market.

There exist CGE models that focus on a very small area and its interaction with the rest of the world. The scope of equilibrium models is, nevertheless, mostly much wider than econometric models and programming models. In many of the large simulation models (either partial or general equilibrium models), the level of aggregation does not allow to model adequately the new policy instruments of the Common Agricultural Policy (CAP), such as allocation distortions due to decoupled direct payments (Salvatici *et al.*, 2000). An alternative is to use mathematical programming models, which is the focus of this dissertation. An advantage is that the computational power of mathematical programming (MP) allows much greater disaggregation for the analysis of effects at farm level (Preckel *et al.*, 2002).

Mathematical programming (MP) has become an important and widely used tool for analyses in agriculture and economics. The basic motivation for using programming models in agricultural economic analysis is straightforward, because the fundamental economic problem is making the best use of limited resources (Mills, 1984). The use of optimisation models is therefore a perfect combination with the neoclassical economic theory, which perceives economic agents as optimisers. The use of programming models can, however, also capture elements of other basic economic theories such as the new institutional transactions cost theory, which assumes that agents minimize the transaction costs.

MP has evolved considerably, losing the features of a pure farm management instrument. Presently, it is an important instrument of policy analysis at the regional, national as well as EU level, with the objective of analysing the impact of agricultural policies on supply and on the socio-economic and environmental systems linked to the farming sector (Salvatici *et al.*, 2000).

An MP model can formally be described as follows:

$$\text{Maximize } f(x_j) \quad (1)$$

Subject to

$$g_i(x_j) \leq b_i \quad (2)$$

The objective function $f(x_j)$ together with the optimising operand reflect the goals set by the decision makers, with x_j as decision variables. In a farm model, the objective function often comprises a profit function. The b_i elements specify the limited resources or factor endowments faced by farmers and $g_i(x_j)$ indicate how much each decision variable x_j contributes to the use of the limited resource.

An MP model can easily simulate the effect of different policy instruments at the individual farm level:

- price adjustments (price support, taxes, subsidies) can be captured through changes in $f(x_j)$;
- command-and-control measures which impose new technologies are introduced by new x_j with corresponding new parameters in $f(x_j)$ and $g(x_j)$;
- changes in b_i reflect imposed changes in factor endowments (e.g. quota).

The most important argument for using MP in agricultural policy analysis is the possibility to model straightforwardly the link between economic elements and bio-physical and ecological elements of the farm. Although other techniques may also allow for incorporating the joint non commodity output production, MP models offer unique advantages over other methods of agricultural sector analysis because of being able to address the multivariant and highly interlinked nature of agriculture (Hazell and Norton, 1986).

More recently, a renewed interest in programming models is observed. Partly confirming the above-mentioned advantages, Heckelei and Britz (2005) distinguish three developments that may explain this evolution. First, they mention the switch from price support to other policy instruments with farm-specific ceilings, such as the dairy quotas, set-aside obligations, stock-density restrictions. Second, there is the increased interest in multifunctionality. Third, the possibility of the introduction of restrictions, such as the land balance and animal feeding requirement constraints, prevents implausible results and thus enhances the credibility of optimisation exercises.

Another crucial factor is the theoretical evolution of mathematical programming and the calibration of it in recent years. This has moved from traditional linear and quadratic programming to Positive Mathematical Programming (PMP) and to different types of techniques to introduce econometrics into MP such as combination with maximum entropy estimators (Paris and Howitt, 1998); Symmetric Positive Equilibrium Problem (SPEP) (Paris, 2001) or the estimation of constrained optimisation models (Heckelei and Wolff, 2003). The calibrated MP models aim at analysing explicitly the effects of agriculture policies at regional or sector levels using information sets that were considered insufficient for earlier methodologies (Arfini, 2001).

A final incentive to use MP is the close link between model elements and real world constraints, which enhances the comprehensibility of the model and the results for policy makers. As such, MP can be seen as a communication facilitating instrument for the various stakeholders in a changing policy environment, in particular the farmer and the policy-maker (Fernagut *et al.*, 2004).

Objective: description of 3 types of MP

The introduction has, so far, mainly motivated the focus of the dissertation: farm-level mathematical programming modelling. The rest of the dissertation is devoted to the description, application and critical assessment of three mathematical programming approaches, of which the choice depends on the type of problem and the availability of historical data.

In the dissertation, a distinction is made between:

- Purely normative mathematical programming (NMP) models, that simulate an optimal solution among possible solutions using a predefined decision rule.
- Positive mathematical programming (PMP) models, that incorporate observed behaviour to calibrate the normative simulation behaviour.
- Econometric mathematical programming models (EMP) that use more advanced econometric techniques to calibrate parameters used in the decision model.

The objectives of this dissertation are to describe these types of MP models in detail, to develop tools based on the three types of programming models for agricultural policy support and to apply the developed tools on specific cases. The applications should prove the usefulness of the models for policy analysis and can lead to policy recommendations. However, due to the wide variety of topics and particularities of each of the applications, these recommendations should be looked upon separately and do not form topics for the main conclusions of the dissertation. Instead, in the conclusion of the dissertation, an overview is made to identify the strengths and weaknesses of the different models applied, according to the dimensions of the applications such as the purpose of the model and the intended users.

The dissertation consists of a compilation of contributions in international peer reviewed journals, books and proceedings[2]. To situate these different contributions into the general structure of the dissertation, each chapter starts with a short overview and an explanation of the role of the chapter within the general framework and ends with lessons leaned from the modelling exercise.

The outline of the dissertation is presented in Figure 1. Chapter 1 introduces the three types of programming models, NMP, PMP and EMP, followed by an illustration of the similarities and differences between NMP and PMP with a simplified dairy farm model that simulates the uptake of meadow bird management. Chapter 2 presents an application of an NMP model to simulate the influence of management decisions on the nutrient balance of a dairy farm and ends with a critical discussion of the strengths and weaknesses of NMP in this case. Chapter 3 elaborates on the calibration concept and the application of it in PMP. Chapter 3 presents also the farm-level PMP model SEPALE that is used as base model in chapter 4 and 5. Chapter 3 ends with a simulation with SEPALE of the June 2003 CAP reform options and with an evaluation of PMP and SEPALE. Chapter 4 extends the base model SEPALE with a module to deal with sugar quota and presents simulation results of the sugar Common Market Organisation (CMO) reform options. Chapter 5 applies the concept of EMP to the sugar module that has been described in chapter 4. Chapter 5 also provides more detailed results for 4 groups of farms with a different reaction to the simulated sugar regime reforms. Finally, the general conclusions of the dissertation and tries to provide more comprehensive insights for future developments of models for agricultural policy support.

[2] Each contribution is the result of collaboration with other research groups. Parts of the text of the dissertation are written by the co-authors of these papers.

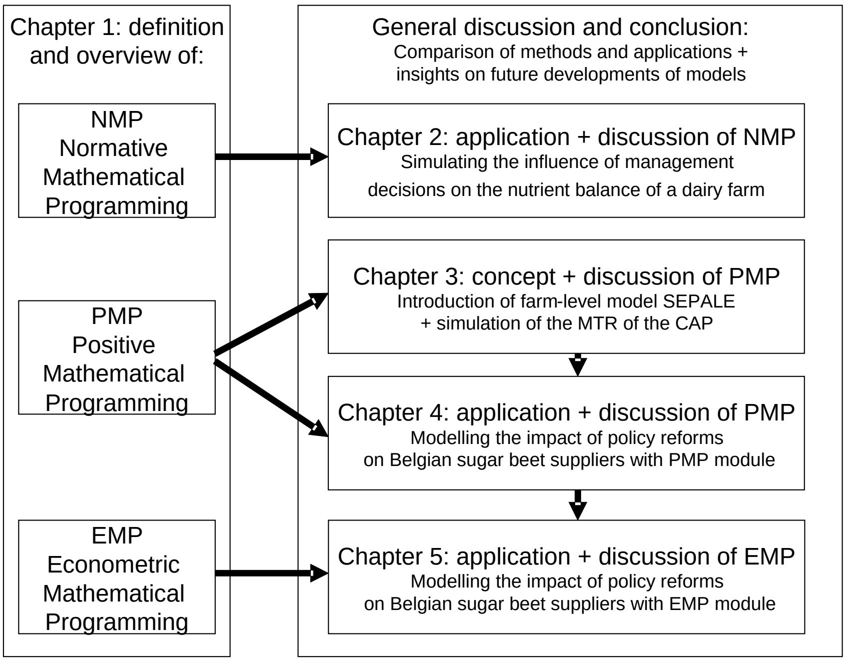

Figure 1. Outline of the dissertation

Chapter 1 Overview of the three types of programming models

This chapter starts in the introduction with the explanation of mathematical programming and duality followed by the presentation of three mathematical programming approaches, of which the choice depends on the type of problem and the availability of historical data. First is shown how normative mathematical programming (NMP) can help to simulate the impact of new activities when historical data are scarce. The second approach is Positive Mathematical programming (PMP), which allows taking both historically observed behaviour and new normative information into account. The similarities and differences between both approaches are illustrated with a toy-size dairy farm model that simulates the uptake of meadow bird management. Finally, a more advanced programming technique, Econometric Mathematical Programming (EMP), is introduced combining the advantages of econometrics and programming techniques.

Parts of this chapter have been published as

Buysse, J., Van Huylenbroeck, G. and Lauwers, L. (2006). Normative, positive and econometric mathematical programming as tools for incorporation of multifunctionality in agricultural policy modelling. Agriculture, Ecosystems & Environment, in press.

1.1 Introduction

Before presenting the three MP approaches that can be used, this introduction explains the basic idea of MP and the ‘duality’. Following linear programming model in its primal form illustrates the use of mathematical programming in agricultural economics:

$$\max Z = \sum_j c_j x_j \qquad (3)$$

Subject to:

$$\sum_j a_{ij} x_j \leq b_i \qquad (4)$$

$$x_j \geq 0$$

where:

c_j is the forecasted gross margin of farm activity j,

x_j is the level of farm activity j,

a_{ij} is the quantity of resource i required to produce one unit of activity j,

b_i is the amount of available resource i,

i is the index of resource and j is the index of activities.

The solution of this primal model gives information on which activities should be chosen to maximise the gross margin. The primal model provides, however, no information how to increase the gross margin by acquiring additional resources i. Therefore, we have to calculate the marginal value product of each resource i (in programming literature this is also called the shadow cost of the resources).

The dual problem is the linear programming model specified to find these shadow prices λ_i for the fixed resources i. We can solve thus actually two problems: the primal resource allocation problem, and the dual resource valuation problem. The study of duality is very important in MP because duality increases insight into MP solution interpretation (Hazell and Norton, 1986). The dual problem can be stated as follows:

$$\min W = \sum_i b_i \lambda_i \qquad (5)$$

Subject to:

$$\sum_i a_{ij} \lambda_i \geq c_j \qquad (6)$$

$$\lambda_j \geq 0$$

The shadow costs λ_i found by the dual problem correspond to the Lagrange multipliers that are used in the first-order optimality conditions of the primal MP model (also called the Kuhn-Tucker conditions or complementary slackness conditions). Duality is here for comprehensibility reasons illustrated for linear MP models, but it applies to non-linear models as well.

The concept of duality is important and is used in all thee MP methods that are presented in the following subsections of this chapter.

1.2 Normative mathematical programming (NMP)

1.2.1 Arguments for using NMP in agricultural policy analysis

NMP has been used in agricultural economics for more than 50 years. This prescriptive type of model starts from a decision rule of the decision maker, which determines the levels of the different variables when aiming to optimise the objective set by the decision maker (Hazell and Norton, 1986). Usually, this concerns utility maximisation from a private economic viewpoint. Both the targets and the decision variables can comprise economic, ecological or social aspects of the system, which again highlights the possibility of a multidisciplinary approach in programming models. An extension to multi-objective and goal programming techniques even allows finding the best compromise in the case of conflicting objectives (Romero and Rehman, 1989).

In the NMP models, parameters of the objective function and constraints are not calibrated to historical data. This means that for constructing an NMP model, basic knowledge of the system is sufficient. The disadvantage is that NMP does not guarantee that the observed or baseline data are reproduced.

McCarl and Spreen (2004) put the numerical usages of NMP into four subclasses: 1) prescription of solutions; 2) prediction of consequences; 3) demonstration of sensitivity; and 4) solution of systems of equations. Although prescription of solutions is perceived as the basic function of mathematical programming, it is probably the least common in practice. The reason is that because of the normative character of NMP models, decision-makers often do not trust the policy model results sufficiently to replace own judgement. Prediction of consequences and demonstration of sensitivity are therefore, usually combined, more important for agricultural policy support (Pannell, 1997). Finally, the solution of systems of equations is similar to a technical device in empirical problems and therefore only indirectly applicable for policy analysis.

For the prediction of consequences, the policy makers are interested in the comparison between the currently applied policy, called the baseline, and the alternative policy options. In order to be valid, the policy analysis model in its baseline run must reproduce the observed situation as close as possible. Because of the lack of adequate calibration mechanisms, NMP does not guarantee that such a validation exercise will be a success.

This disadvantage of NMP can be explained with the simplified NMP model illustration in Figure 2. The graph shows the production possibilities for a farm with two crops, X1 and X2. The objective function of the farm is to maximise its profits. The NMP iso-profit line is thus determined by the price and cost ratios of the two crops. The optimal solution can be found by parallel shifting the iso-profit line away from the origin. The point with the largest distance to the origin within the convex hull of constraints is the optimum. In the case illustrated in Figure 2, point ‘a’ is the maximum, reflecting the situation that the optimal crop mix does not correspond to the observed production. The distance between the observed point “a” and the optimal point is due to the fact that the values of the technical coefficients and variable costs in the model are different from the real ones or because not all constraint are represented in the model. This results in different ratios between prices and costs of the two crops and creates a difference between the observed solution and the optimal solution.

Variation of the price or cost ratios causes changes in the slope of the iso-profit line. The graph representation of the NMP decision problem also makes clear that with relatively small changes in the iso-profit line, the corner point ‘a’ will remain the optimum. Only with a large change in slope of the iso-profit line, the maximum jumps abruptly to corner point ‘b’. Besides the fact that the NMP solution does not reflect the observed situation, the staircase situation between the corner point solutions is a second disadvantage of NMP. The staircase stituation poses more problems to regional models than to farm models because individual farms are more likely to react abruptly than the sum of all farms from a region.

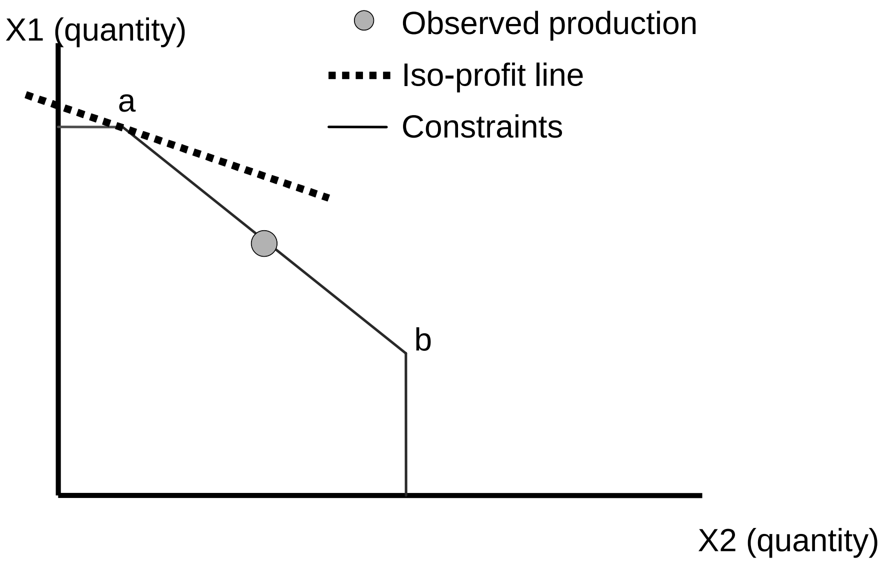

Figure 2. Graphical illustration of a simplified NMP farm model with two activities (X1 and X2) and a profit maximising objective function.

Despite the disadvantages, there are several motivations for continuing to apply NMP. The first and most important one is, when confronted with new policies or farm practices, the lack of empirical data that sufficiently describe the system in a baseline situation. Empirical data could be unavailable because the modelled activity is very novel or when the model scope is too detailed.

The second reason for still using NMP is the fact that one is not always interested in the optimal situation itself neither whether it reflects baseline. The design and use of NMP can also help to understand a problem and to discover relevant decision variables and constraining factors. A calibration procedure may be obsolete for this case.

The third reason is that a number of methodological developments in the field of MP attenuate the disadvantages mentioned above. The inclusion of more economic theory and observed institutional and economic reality results in better validated models (Hazell and Norton, 1986). While the first applications relied on linear programming because of the available algorithms to solve this type of problems, current models can, thanks to improved solver and computer equipment, also include nonlinear functions, resulting in less staircase situations. Moreover, the development of multi-objective and goal programming techniques, allowing the trade-off between conflicting objectives, has resulted in certain areas (such as, e.g., modelling of water policies) in a renewed interest for NMP (see e.g. Gomez-Limon *et al.*, 2002; Gomez-Limon and Riesgo, 2004).

The following subsection demonstrates the applicability of NMP with an illustrative example.

1.2.2 Normative model to predict participation to meadow bird management

The illustrative model tries to analyse the participation level of a farm to an agri-environmental scheme to protect meadow birds. The agri-environmental scheme (AES), as applied in Flanders, compensates the income loss of farmers in case they switch to more extensive grassland management in order to protect meadow birds. The meadow bird management implies delayed fertilisation and a lower stock density, resulting in lower grass yield and quality. The meadow bird population can only develop in extensively managed grassland, whereas the farmer tries to intensify the grassland management to have a higher grass yield.

The model describes a simplified hypothetical dairy farm with the possibility to produce milk, maize, and intensively and extensively managed grassland. Maize can be sold or used as fodder on the farm, while grass only serves as fodder and can not be sold. The dairy farm has revenues from the milk sold, maize sold and from the subsidies for extensively managed grassland. The NMP model of the dairy farm maximises a profit function subject to a land constraint, milk quota constraint and feeding constraints. The feeding constraints are based on the Dutch VEM-DVE system (CVB, 1996). The requirements and the supply of protein are expressed as *Darm Verteerbaar Eiwit* (DVE), the protein actually digested in the small intestine, and the requirements of energy are expressed as *Voeder Eenheid Melk* (VEM) or Feed Unity Milk.

In matrix notation the model can be stated as follows:

$$Z = \mathbf{p'} \mathbf{(x - z)} + \mathbf{a'} \mathbf{S} \mathbf{x} - \mathbf{c'} \mathbf{x} \qquad (7)$$

Subject to:

$\mathbf{a'} \mathbf{x}$ - available land ≤ 0	[landprice]	(8)
vemneeded x_{milk} - $\mathbf{vemsupply'}\ \mathbf{z} \leq 0$	[VEMprice]	(9)
dveneeded x_{milk} - $\mathbf{dvesupply'}\ \mathbf{z} \leq 0$	[DVEprice]	(10)
x_{milk} - Quota ≤ 0	[quotarent]	(11)
$\mathbf{z} - \mathbf{x} \leq 0$	[λ]	(12)

$x \geq 0$, $z \geq 0$, landprice ≥ 0, VEMprice ≥ 0, DVEprice ≥ 0, quotarent ≥ 0, $\lambda \geq 0$

where:

i is the index of the different products (milk, maize, extensive grassland, intensive grassland)

x is a (i x 1) column vector of production quantities,

z is a (i x 1) column vector of self consumption of products,

p is a (i x 1) column vector of output prices per unit of production quantity (with zero elements for grassland),

c is a (i x 1) column vector of average cost per unit of production **x**,

a is a (i x 1) column vector of technical coefficients determining how much resource base (i.e. farmland) is needed per production quantity x_i (zero element for milk),

S is a (i x i) diagonal matrix of subsidies per unit of resource base (i.e. farmland),

vemneeded and dveneeded are parameters that determine how much energy (expressed in VEM) and proteins (DVE) are required to produce a quantity of milk x_{milk},

vemsupply and **dvesupply** are (i x 1) column vectors that indicate how much VEM and DVE is supplied by a quantity of fodder z (zero elements for milk).

For illustration purposes, this simplified model has been applied to a hypothetical dairy farm with quota of 250 tonnes of milk and 20 ha of land. The other main characteristics of the farm are summarised in Table 1.

Table 1. Characteristics of the hypothetical farm

	p (euro/tonne)	c (euro/tonne)	a (ha/tonne)	vemsupply (VEM/tonne)	dvesupply (DVE/tonne)	Vemneeded (VEM/tonne)	Dveneeded (DVE/tonne)
Milk	200	50	0	0	0	800	60
Maize	80	60	0,06	940	55	0	0
Intensive grassland	0	55	0,1	920	80	0	0
Extensive grassland	0	55	0,2	840	65	0	0

The product quantities **x** (milk) and **z** (maize and grassland) are the decision variables in the model. Landprice, VEMprice, DVEprice, quotarent and λ are the dual variables in the model. They show the increase of the objective function when the constraints become more relaxed. The level of **p**, **c**, **a**, **vemsupply** and **dvesupply** are given and constant during simulation. The level of subsidies for extensively managed grassland in matrix **S** is the external policy parameter and can be changed. Changing **S** simulates the impact of varying compensation levels for managing grassland extensively on the uptake of this agri-environmental scheme.

The result of the simulation exercise is presented in Figure 3. Figure 3 illustrates that the numerical example has four corner solutions. For compensation levels lower than 200 euro/ha, the feeding requirements are filled with intensive grassland and maize. A part of the maize is sold and there is no extensive grassland. For compensation levels from 250 to 650 euro/ha, 5 ha of extensive grassland is included in the model and used for feeding and no maize is sold. For 700 euro/ha compensation, the milk quota is not filled and only 4 tonne of intensive grass is produced. For 750 euro/ha and higher compensation levels, all grassland is extensively managed.

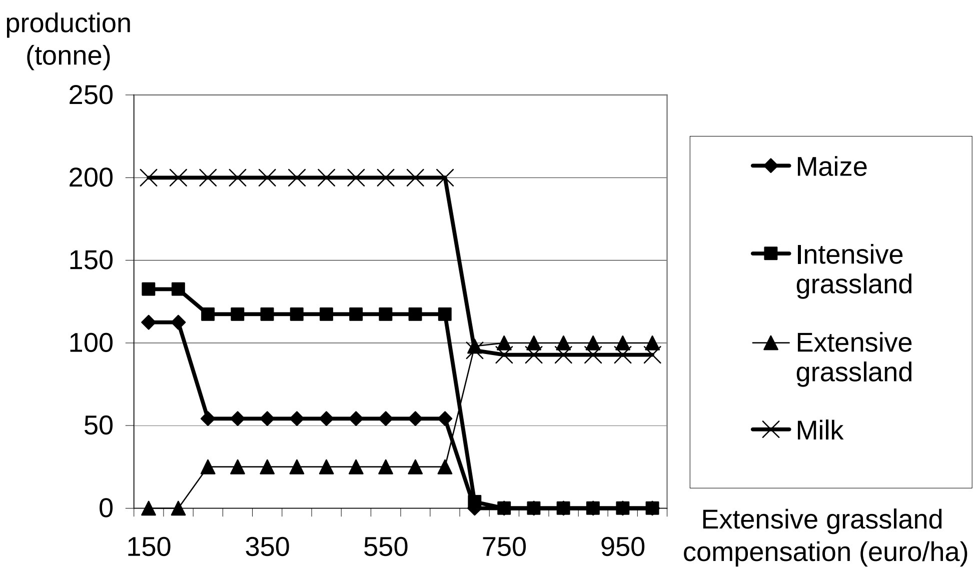

Figure 3. The impact of the compensation level for extensively managed grassland on the production of the different activities on the dairy farm

The normative character of the simulations implies that the model outcomes must be interpreted as uptake potentials rather than as predicted uptake of this environmental scheme. However, as far as these results remain close to the actual potential that can be detected and stimulated by farm advisory experts, they also enable descriptive analyses. In any case, they can inform decision-makers of potential reactions of farmers on incentives provided.

By introducing changes in the other parameters (**c**, **a**, **vemsupply** and **dvesupply**) that are constant during simulation, the impact of underlying farm characteristics could be analysed. This allows analysis of how farms with different characteristics react to the same incentives. Finally, the model can also serve as a tool for analysing the sensitivity of the results for changes in the decision-making environment, such as changes in market prices **p** or policy interventions in other activities than the extensively managed grassland through **S**. As such the model could be used as a policy impact analysis tool.

Normativity and uncertainty of these external factors, however, call for specific needs with respect to the organisation of information production and communication of information. The advantage of NMP in this case is that it allows for incorporating expert knowledge and (if coupled to an attitude model) behavioural factors, which makes the prediction more realistic. Despite the normative character of the economic potential models, they can serve as a laboratory where the policy analyst can simulate a wide range of policy options.

1.3 Positive mathematical programming (PMP)

1.3.1 Calibration of farm-level MP models

Positive mathematical programming models have been developed to overcome the normative character of NMP. Contrary to NMP models, in PMP some parameters are adjusted to be able to reproduce exactly a given baseline. Because this type of model reproduces observed data, the method is called positive. The main purpose of this descriptive type of model is to explain producer’s reactions to external changes, which makes PMP models extremely interesting for policy makers.

The main argument to build PMP models is the increase in reliability through avoiding the difference between the empirical baseline situation and the simulated baseline situation, but also to reproduce the behaviour of farmers in their specific environment according the few data that are available and reflecting farm decision process: use of land and production quantity. PMP, as originally proposed by Howitt (1995a), is considered as the most widely applied method for calibration of an MP model. In this dissertation, we describe MP calibration in a more generalised way, of which the original PMP approach (Howitt, 1995a) is a special case. Nevertheless, we call the more general approach also PMP, because it encloses all published variants on PMP (for an overview, see Heckelei and Britz (2005) and Henry de Frahan *et al.* (2006)).

Figure 4 uses a simplified model to explain the basic idea behind PMP and the comparison of Figure 4 and Figure 2 illustrates the differences between NMP and PMP.

In contrast to NMP, PMP starts from the concept that the activity mix observed at the farm is optimal and reflects the farmer behaviour considering all the constraints (visible and not), the production level, the technology and the hidden cost of farm choice relating the used technology and land allocation.

The main idea is that it is sometimes easier to reproduce a proxy of the technology than the technology itself and that the cost function (alias the cost of the technology) is the dual of the production function (alias the technology) and, thus, a proxy for the technology. Because it is impossible for the modeller to find out information related to used technology and production cost, a non linear cost function able to capture the variable cost associated with the dual price of the constrained factors and the activity level is calibrated. In the example in Figure 4, a convex non-linear cost function is put into the profit function resulting in a concave total profit function. The parameters of the objective function are adjusted to reproduce exactly the baseline.

Because of the calibration and the non-linear function in the model, PMP avoids two of the drawbacks of NMP: problems of reproducing the baseline and the staircase situations. It is clear that the positive attribute is not an objective but instead a specific characteristic of the methodology, as in econometric methodology, and the calibration phase is the step adopted in order to reach the character of a positive model. Of course the main goal of this type of models is to simulate farm behaviour according to some policy scenario referred to real farms and not to hypothetical farms. In this sense the normative character is needed but in a second step and for this reason it is possible to define these models as positive-normative models.

The possible numerical use of PMP is, however, more limited than NMP. PMP can not be used to find prescriptive solutions for farms about their optimal activity mix because PMP assumes their choice is optimal. On the other hand, PMP is very practical for prediction of consequences and demonstration of sensitivity as long as enough empirical data are available for calibration of the model.

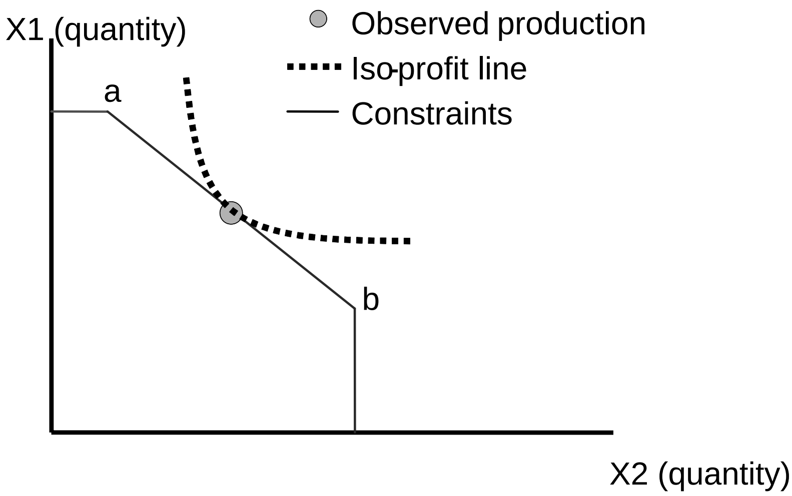

Figure 4. Graphical illustration of a PMP simplified farm model with two activities (X1 and X2) and a profit maximising function

The first prerequisite for building a PMP model is a proper definition of the model. Definition of the model comprises the choice of the functional form of the objective function and constraints and the definition of endogenous variables, exogenous variables and parameters to be calibrated.

Starting from the final simulation model we have in mind, the optimality conditions are derived for calibrating the model. Both the necessary and the sufficient conditions for an optimum must be satisfied. For an MP model with a non-linear objective function and linear constraints, the so-called Kuhn-Tucker conditions form the necessary conditions. Moreover, these Kuhn-Tucker conditions are also sufficient for a maximisation problem if the objective function is quasi-concave with quasi-convex constraints or for a minimisation problem if the objective function is quasi-convex with quasi-concave constraints (Mills, 1984). Therefore, the Kuhn-Tucker conditions form the set of calibration equations.

For calibration, enough empirical data should be gathered to have zero degrees of freedom in the calibration equations. In practice, however, data availability is often not sufficient resulting in the need for using additional (and sometimes ad hoc) assumptions. Various authors have proposed different types of assumptions. The original, and until now most applied PMP version (Howitt, 1995a), uses in a first phase an additional MP model with calibration constraints to assign the unknown dual values of the resource constraints. This approach assigns the highest possible value to the dual variables of the resource constraints that still make a perfect calibration possible[3]. For an overview of the variations on the original approach by Howitt (1995a), we refer to Henry de Frahan *et al.* (2006). Instead of taking the highest possible value for the duals of the resource constraints, other authors (Judez *et al.*, 2001; Heckelei and Britz, 2005; Henry de Frahan *et al.*, 2006) suggest using as much as possible available information about prices of resource constraints as a proxy for the dual values.

However, not all authors agree to use external values (as proxy of dual values) for calibration of an MP model by PMP. In particular Paris (1997, 2001), Paris and Arfini (2000) and Paris and Howitt (1998), suggest to avoid external values in order to avoid "contamination" of the observed data. Their concern is related to the fact that external values allow to calibrate the model according the Langrangian function and the obtained variable cost, but don't represent the real "internal" dual value for a given specific farm.

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[3] The dual value of the resource constraints of phase 1 of original PMP is the highest possible if it is assumed that the total cost correspond to the sum of the observed accounting costs used in phase 1 of PMP and some potential unobserved costs. These observed accounting cost define then a minimum for the calibrated total cost function.

To demonstrate the principles of PMP, we transform in the next subsection the illustrative NMP model of section 1.2.2 into a PMP variant.

1.3.2 PMP model to predict participation to meadow bird management

To demonstrate the PMP approach for the same problem as in section 1.2.2, we suppose that we already have some observations of farms participating to the meadow bird management program. Table 2 contains empirical data that could be gathered from management programs that are in place for some time and are adopted by two farms. The parameters on costs, prices and yields of both farms are the same as in Table 1, except that Farm 2 has 10% higher costs. The NMP model presented in the previous section could then be validated against these empirical data. The validation results show that the NMP model of section 1.2.2 does not reproduce the baseline.

Table 2. Empirical data of two hypothetical farms under the assumption of a 300 euro/ha compensation for extensive grassland

	Farm 1		Farm 2	
	Observed*	Simulated by NMP*	Observed*	Simulated by NMP*
Production				
Milk	200	200	250	236
Maize	133	54	133	73
Extensive grassland	100	117	110	0
Intensive grassland	10	25	5	136
Self consumption				
Maize	100	54	133	73
Extensive grassland	100	117	110	0
Intensive grassland	10	25	5	136

Because of the availability of empirical data, the illustrative model can be turned into a PMP variant. The objective function consists again of a profit function but now it includes a quadratic functional form for its cost component. In matrix notation, this gives:

$$Z = \mathbf{p}' (\mathbf{x} - \mathbf{z}) + \mathbf{a}' \mathbf{S}\, \mathbf{x} - \mathbf{x}' \boldsymbol{\alpha}\, \mathbf{x} / 2 - \boldsymbol{\beta}' \mathbf{x} \quad (13)$$

where:

$\boldsymbol{\alpha}$ is an (i x i) diagonal matrix of quadratic cost function parameters,

$\boldsymbol{\beta}$ is an (i x 1) column vector of linear cost function parameters.

Model (13) is extended with the same land, quota and feeding constraints as model (7). Again, the production quantities **x** and **z** of the model are the decision variables. Calibration determines the cost function parameters in the matrix $\boldsymbol{\alpha}$ and vector $\boldsymbol{\beta}$ and the cow productivity parameters: VEMneeded and DVEneeded. Prices (**p**) and Subsidies (**S**) are exogenous to the model.

This model (13) has a concave objective function with convex constraints. Now, the calibration conditions are derived from the Kuhn-Tucker conditions of model (9). In its Langragian form this model can be written as follows:

$L = \mathbf{p}' (\mathbf{x} - \mathbf{z}) + \mathbf{a}' \mathbf{S}\, \mathbf{x} - \mathbf{x}' \boldsymbol{\alpha}\, \mathbf{x} / 2 - \boldsymbol{\beta}' \mathbf{x}$ - landprice ($\mathbf{a}' \mathbf{x}$ - available land) - VEMprice (vemneeded x_{milk} - $\mathbf{vemsupply}' \mathbf{z}$) - DVEprice (dveneeded x_{milk} - $\mathbf{dvesupply}' \mathbf{z}$) - quotarent ($x_{milk}$ - Quota) - λ $(\mathbf{z} - \mathbf{x})$

For comprehensibility reasons, only the relevant equations for calibration are given here in algebraic notation:

$(\partial L/\partial \text{VEMprice})\ \text{VEMprice} = 0 \Rightarrow$ (for a strictly positive VEMprice)

$$\textstyle\sum_i z_i\ \text{vemsupply}_i = \text{VEMneeded}\ x_i \quad (14)$$

$(\partial L/\partial \text{DVEprice})\ \text{DVEprice} = 0 \Rightarrow$ (for a strictly positive DVEprice)

$$\textstyle\sum_i z_i\ \text{dvesupply}_i = \text{DVEneeded}\ x_i \quad (15)$$

$(\partial L/\partial z_i)\ z_i = 0 \Rightarrow$ (for every strictly positive z_i)

$$-p_i - \lambda + \text{VEMprice vemsupply}_i + \text{DVEprice dvesupply}_i = 0 \quad (16)$$

$(\partial L/\partial x_i)\ x_i = 0 \Rightarrow$ (for every strictly positive x_{maize}, $x_{intensivegrass}$, $x_{extensivegras}$)

$$p_i + \lambda + a_i\, s_i - \alpha_i\, x_i - \beta_i - a_i\ \text{landprice} = 0 \quad (17)$$

substituting (16) in (17) results in following calibration equations for every fodder crop:

$$\text{VEMprice vemsupply}_{fodder} + \text{DVEprice dvesupply}_{fodder} + a_{fodder}\, s_{fodder} - \alpha_{fodder}\, x_{fodder} - \beta_{fodder} - a_{fodder}\ \text{landprice} = 0 \quad (18)$$

$(\partial L/\partial x_{milk})\ x_{milk} = 0 \Rightarrow$ (for the strictly positive x_{milk})

$$p_{milk} + a_{milk}\, s_{milk} - \alpha_{milk}\, x_{milk} - \beta_{milk} - \text{VEMprice vemneeded} - \text{DVEprice dveneeded} = 0 \quad (19)$$

The parameters VEMneeded and DVEneeded can be assigned from equations (14) and (15). To calibrate α_i and β_i, the observed average cost **c** can be used as additional information in the calibration as follows (in algebraic notation for every activity i):

$$\mathbf{c}_i = \alpha_i x_i / 2 + \beta_i \qquad (20)$$

In order to obtain zero degrees of freedom in the calibration equations (18), (19) and (20), additional data have to be gathered for the dual variables landprice, VEMprice and DVEprice. If we suppose a landprice of 250 euro/ha on Farm 1 and 200 euro/ha on Farm 2, a VEMprice of 0.070 euro/kVEM and a DVEprice of 0.268 euro/kg DVE, α and β can be calibrated as follows:

$$\alpha_{fodder} = 2\,(\text{VEMprice vemsupply}_{fodder} + \text{DVEprice dvesupply}_{fodder} + a_{fodder}\, s_{fodder} - a_{fodder}\, \text{landprice} - c_{fodder}) / x_{fodder} \qquad (21)$$

$$\alpha_{milk} = 2\,(p_{milk} + a_{milk}\, s_{milk} - \text{VEMprice vemneeded} - \text{DVEprice dveneeded} - c_{milk}) / x_{milk} \qquad (22)$$

$$\beta_i = c_i - \alpha_i x_i / 2 \qquad (23)$$

Once model (13) is calibrated, changing the exogenous variables **p** and **S** can simulate different policy alternatives. Figure 5 shows the response of the two hypothetical farms on an increasing compensation for meadow bird management. The difference in results for both farms can be explained by differences of the economic situation between the farms. Farm 1 has, in its baseline, excess fodder production resulting in sales of maize. An increase in subsidies for extensive grassland first reduces the production and the selling of maize. For compensation levels higher than 800 euro/ha of extensive grassland, Farm 1 has almost no excess fodder production anymore and, therefore, the linear increase in extensive grassland slows down. Farm 2 has in the baseline no excess fodder production. For this reason, switching to meadow bird management is more difficult.

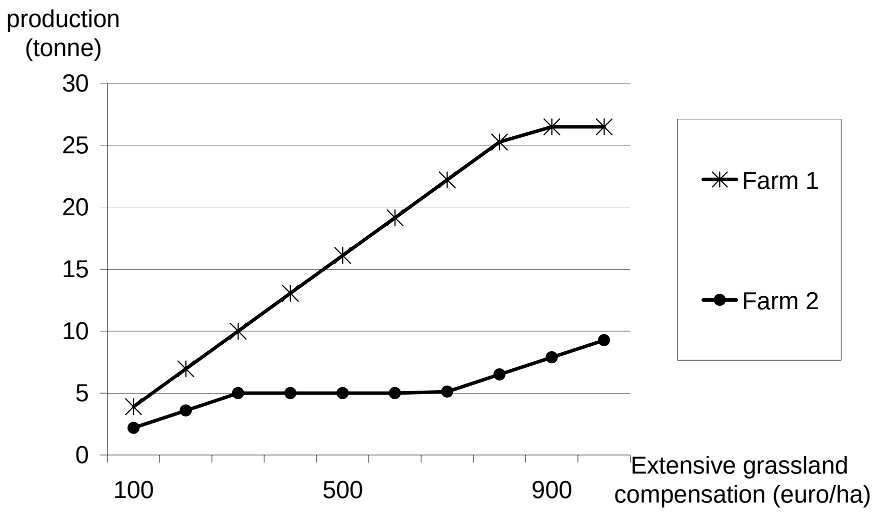

Figure 5. The impact of the compensation level for extensively managed grassland on the production of the extensively managed grass on the dairy farm

The illustrative example shows very well that PMP is able to simulate different reactions based on the observed empirical data. Not only PMP proves its value to analyse the differences between farms. But also, when bringing the information of a sample of individual farm models together, PMP allows to build sector models (see e.g. Buysse *et al.*, 2005a). Moreover, such a model can implicitly simulate transactions between farms and individual farmers' behaviour, depending on their situation and past behaviour. This results in more balanced and realistic simulations of intended policies.

The PMP approach is already applied by various authors for simulating policy responses. Own research with PMP has resulted in the so-called SEPALE model for Belgian agriculture with applications on the June 2003 CAP reform (including modulation of payments) (Henry de Frahan *et al.*, 2006) and on the sugar reform (Buysse *et al.*, 2005a) (see also chapter 3.5 and Chapter 4).

These applications highlight that the main advantage of PMP, namely that it allows prediction based on past observations of the cost function and thus real farmer's behaviour. It incorporates individual data, derived from real accountancy data. As such, it allows to differentiate results according to farm types, farm size or farm location. This aspect becomes important for policy analysis evaluation because it allows giving to public stakeholder and policy maker a realistic picture on the effects of a given policy using data that they know. Also, the cost of the analysis is relatively small because it is often based on databases already available (as FADN) and it is not necessary specific interviews on farm holdings. So, the unique cost is related to the development of the model. However, the calibration of cost or production functions of activities remains difficult when no real observations are available (e.g. limited past uptake of AES or multifunctional systems). Another disadvantage is that although the farm-based approach opens perspectives for modelling farm interactions, it remains difficult to incorporate the institutional rules and settings.

PMP as presented above requires zero degrees of freedom in the calibration equations. As a consequence, the amount of data that must be gathered is very high or the number of parameters that can be assigned during calibration is limited. Due to this limited number of parameters, PMP models usually have a very simple functional form. When modelling agricultural policies, the number of parameters and the functional form are often too restrictive to capture the complex farmers' and system behaviour. Motivated by these shortcomings of PMP, new approaches are developed in order to answer PMP critiques and to improve policy analysis models. In particular, as briefly discussed in the next section, econometric mathematical programming seems a promising avenue to improve the modelling practice.

1.4 Econometric mathematical programming (EMP)

The limitation of having zero degrees of freedom in the optimality conditions puts a lot of restrictions on the flexibility of the functional form of the model[4], a very heavy burden on the data collection, or both. The approach introduced by Heckelei and Wolff (2003) is, however, in interesting alternative. Heckelei and Wolff suggest estimating the parameters of the programming model by using the optimality conditions as the set of estimation equations. Due to the use of the optimality conditions, the estimated model is able to reproduce the baseline correctly. After the estimation of the parameters, the programming model can be used to do simulations and scenario analysis. This combination econometrics and mathematical programming models creates a new field of empirical investigation, which we would like to call econometric mathematical programming (EMP).

The development of MP is less than econometrics focussed on descriptive analysis. As shown above, descriptive analysis is therefore probably the weakest element of MP models. MP has, however, advantages for explorative research of innovation and radical changes of policy instruments within a context of resource constraints. On the other hand, limitations of econometric analyses include a large data requirement and the inability of the model to deal with changes in the underlying economic structure (Hazell and Norton, 1986).

In the case no behavioural data are available, only NMP can be applied, which uses then data from literature based on experimental data. But in the cases of sufficient data availability, modelling should take full benefit of the advanced techniques in descriptive analysis of econometrics and of the possibility to introduce changes in the underlying economic structure through the mathematical programming side of the approach.

[4] The number of parameters that can be identified during the calibration process of PMP models is limited.

The advantage of an MP model is that it is able to cope with variations in land availability, introduction of new or alternative technologies, production quota, fallow restrictions and environmental regulations. These changes in economic structure are gaining importance when radically new policy mechanisms are applied. This is observed in the CAP where price support has shifted over coupled direct payments to decoupled direct payments. Now, multifunctionality-based intervention introduces the coupling of payments to non-commodity outputs, which again leads to another economic logic and behaviour. Relying on a combination of econometrics and programming is therefore perceived as taking the best of both previous approaches with, on the one hand, the possibility to take into account the past behaviour and on the other, opening the possibility of supplementing the econometric analysis of this past behaviour by normative information on adaptation to new economic realities.

The combination of econometrics and programming models is not new. In order to obtain more realistic simulation behaviour, the objective function or the constraints are often supplemented by externally estimated functions or parameters. This introduces, however, difficulties or even inconsistencies (Heckelei, 2002). The most obvious example of such inconsistencies is the use of externally estimated supply elasticities to build a supply function in a programming model, such as, e.g., in Helming *et al.* (2001). The econometric estimation of supply elasticities implicitly takes all the limitations faced by the farmer into account, e.g. among others the land constraint. If this supply function is appended with additional constraints in the programming model, such as the land constraint, the simulation results will not reproduce the original externally estimated supply elasticities. As a consequence, the underlying structure of the model reflects the constraints twice: once in the econometric estimated supply elasticities and once in the constraints explicitly specified in the model. There exist approaches for getting around this hitch (Heckelei, 2002), but it is more useful to directly apply EMP, meaning that the parameters of objective function and constraints are simultaneously estimated. In this way, the fact that certain resources (such as land) are limited will not be reflected anymore in the simultaneously estimated supply function.

Using EMP for agricultural models has two advantages. First, the limitations of the functional form, inherent to many PMP applications, are attenuated. Second, new activities can be introduced based on estimated functions. We can explain these advantages with our example of the previous sections.

The PMP model of previous section has a cost function with two parameters per activity. An application of EMP, based on observations of several farms or for several years, permits choosing a more flexible functional form. Given these additional parameters in the cost function, the model would capture better the behaviour and attitude of the different farmers.

The second advantage of EMP concerns the innovative aspects of recent policy developments in agriculture. If data exist across several farms with different intensity of grassland management, a relationship could be estimated between intensity of management and the costs, yields and revenues of grassland in an EMP model. Given this relationship, the reactions of farmers to a meadow bird management program can be simulated, even if there are no observations of participating farmers.

Different to the NMP approach, EMP is calibrated and can use a function estimated on the calibration data for the relation between management intensity and the yield. The NMP model is not calibrated and uses literature data for the yield of grassland. Different to the PMP approach, EMP allows simulating meadow bird management without actual data on participating farmers while the PMP model of section 1.3.2 needs observations of participation.

1.5 Conclusions

This chapter has described the three mathematical programming approaches that are used and applied in the next chapters of this dissertation. The similarities and differences between the approaches are illustrated with a toy-size dairy farm model that simulates the uptake of meadow bird management. This chapter gives already some indications on the choice of method for a research task at hand. The toy-size model has shown that this choice depends on the type of problem and the availability of historical data. NMP can be applied when historical data are scarce, while PMP and EMP allow taking both historically observed behaviour and new normative information into account. EMP is more robust and theoretically correct than PMP due to the combination of the advantages of econometrics and programming techniques. EMP requires, however, more resources to develop than PMP.

These observations and more experiences with the three MP approaches are further developed in the next chapters of the dissertation.

Chapter 2 An application of farm level NMP: Simulating the influence of management decisions on the nutrient balance of dairy farms

The purpose of chapter 3 is to illustrate an application of an NMP model. The dairy farm model, described in this chapter, is originally developed by Geert Jacobs and Guido Van Huylenbroeck to simulate the willingness to accept extensive grassland management on Flemish dairy farms. In this chapter the original model is adapted and improved to be able to make the simulation exercise presented below. For this study the model was also submitted to a new validation exercise.

The application evaluates the influence of management decisions on the nutrient balance of dairy farms. Three farm systems have been simulated: zero grazing, winter milk and summer milk. From the simulated farm systems the zero grazing farm has in all scenarios the lowest N - surplus. The winter milk farm system has a higher N - surplus than zero grazing but lower than the summer milk farm system. The results further indicate the positive effects of maize feeding in addition to grazing. More maize in the ration is especially good to lower the N - surplus during the grazing period in the summer. The benefits of more maize in the ration decrease when the fertilizer application rates decrease.

Parts of this chapter have been published as:

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2.1 Introduction

There is a growing public concern about the increasing nitrate concentration in drinking water reserves and about the distortion of aquatic ecosystems through eutrophication (Commission of the European Communities, 2002). Excessive nitrogen surpluses can indeed pose a threat on the environment, leading to pollution of water, air and soil (Pau Vall and Vidal, 1999). This has led to the nitrates directive (91/676/EC) of the European Union (EU). This directive aims to protect water from pollution by nitrogen from agricultural resources. In EU countries the major source of nitrogen is mineral fertilizer, while especially in regions of high livestock density, animal manure remains very important. In Belgium and the Netherlands, livestock manure is responsible for more than 50% of the nitrogen inputs on the agricultural land (Pau Vall and Vidal, 1999).

Based on agricultural statistics, it can be calculated that the contribution of cattle in the total manure production in Flanders accounts for 47% of nitrogen and 38% of phosphorus. The pig and poultry sector contribute 39 and 11%, respectively, for nitrogen and 45 and 15%, respectively, for phosphorus (Deuninck *et al.*, 2001). Dairy cattle produce approximately half of the cattle's manure. In the Netherlands too, the dairy sector is an important source of pollution. Dairy farming is responsible for 45 % of the phosphate surplus and 60 % of the nitrogen losses (Van Bruchem *et al.*, 1999). Consequently, in countries as Belgium and the Netherlands, where intensive animal production systems have been developed, a more efficient utilization of dietary nitrogen in dairy farming has a positive impact on the reduction of environmental pollution.

Michiels *et al.* (1998) have compared nutrient balances of 41 Flemish farms. This research has indicated that there are large differences in nutrient use efficiency and that possibilities exist to increase environmental efficiency by changing farm management. Two main approaches have been suggested: (i) an optimisation of the N-utilisation at plant level and (ii) the reduction of N-excretion at animal level. The first approach aims at an optimal application of chemical fertilizer and manure on the land and consequently an adapted choice of crops. The second approach is to optimise the feed mix of the cow in order to increase the nutrient use efficiency at cow level. Both strategies are important but do mutually influence each other. One measure cannot simply be adjusted to another measure (den Boer, 1999 and Thornton and Herrero, 2001). Therefore, in this study a dynamic simulation model, simulating daily plant and animal production, is used to measure the overall impact of management decisions on the nutrient surplus at farm level.

The chapter is organised as follows. In Section 2, the model is described. Section 3 gives some insight in the validation of the model and is followed by a discussion of the results in section 4. Finally section 5 and 6 deal with the discussion and the main conclusions.

2.2 The simulation model

The basic model and underlying mathematical relations is based on earlier work at the department of agricultural economics of Ghent University and is also published in Van Huylenbroeck *et al.* (2000).

The basic idea behind the use of the model for this application is to describe the N and P cycle at farm level based on relationships described in literature. This combined information makes it possible to analyse the overall effect of management decisions on a dairy farm.

The model is based on (i) nitrogen-grassland relations described by Thornley and Johnson (1990), (ii) feeding requirements from Jarrige *et al.* (1988) and CVB (1996), and (iii) lactation functions from Wood (1967) and Wood (1977). These relations allow for calculation of animal and plant production on a daily basis.

2.3 General model

Figure 6 gives a schematic representation of the model, showing how the model combines both plant and animal level.

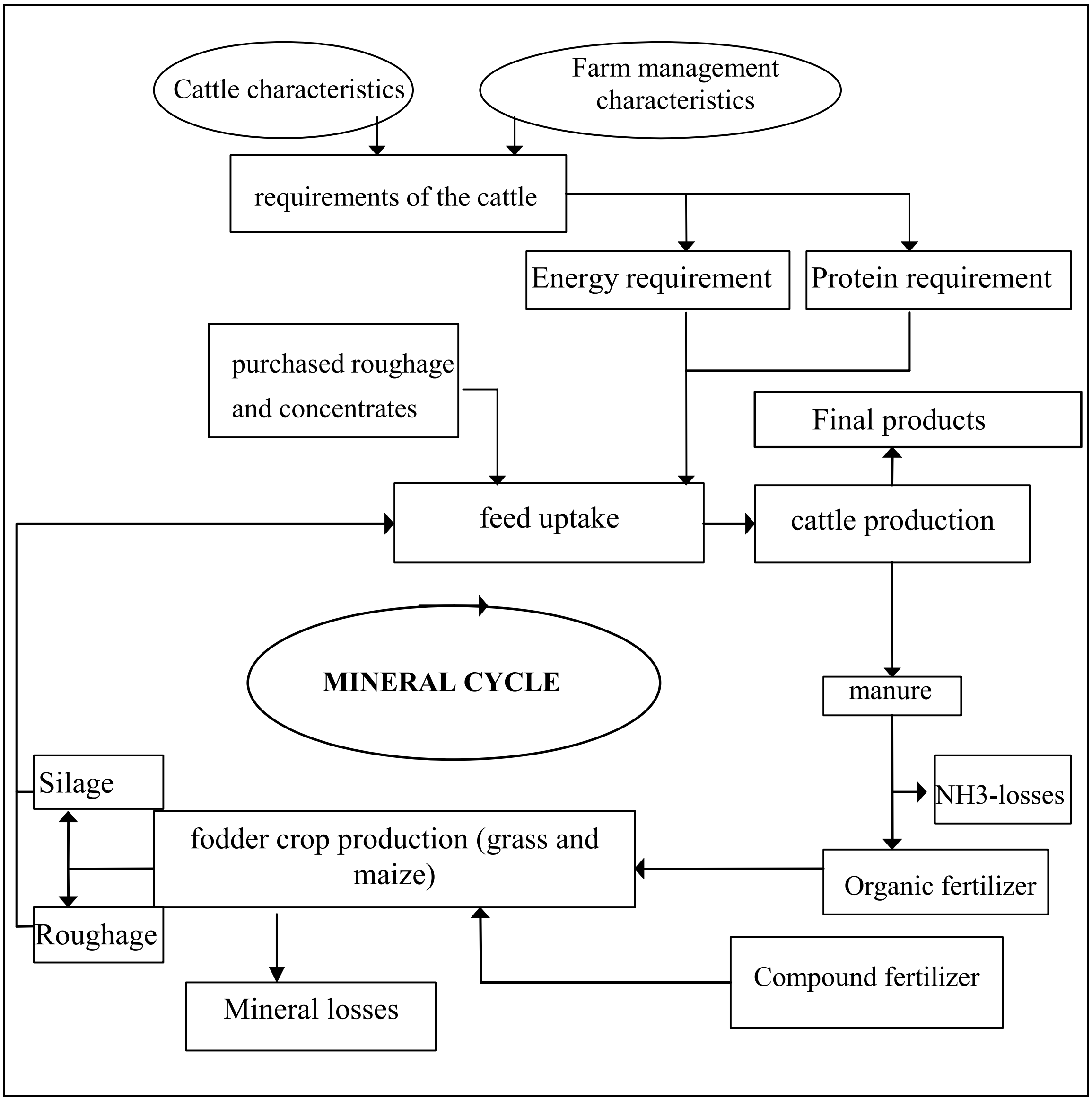

Figure 6. Relationship between different modules in the model

The simulation model was originally implemented in Matlab code. For performance and interface reasons it has been rewritten in Delphi code with the additional benefit that it can also be used as a standalone simulation program. The disadvantage of using Delphi is that there is no optimisation algorithm standard available as is the case in, e.g., GAMS (General Algebraic Modelling System: http://www.gams.com).

In the following sections the model is described in more detail. First the animal production is explained, then the grazing strategy and finally some nutrient cycling aspects.

2.3.1 Animal production

At the start of a simulation, the user of the model has to choose a herd size and its characteristics such as production capacity and calving date. The cows can be clustered into cow groups, of which the data to fill in are summarised in Table 3.

Table 3. Input data for cows

Input data	Unit	Default value
Total production of milk	kg / lactation	7000
Maximum production of milk	kg /day	40
Week in wich the maximum production is reached	week number	8
Lactation period	number of weeks	44
Interlactation period	number of weeks	8
Fat content	% (kg)	3,4
Protein content	% (kg)	4,4

To capture the seasonal variations in weight of the cow and composition of the milk, the model relies on the relationships of Van Arendonk (1985) and Korver *et al.* (1985). Van Arendonk (1985) translates the input of average protein and fat content to a daily fat an protein content. Korver *et al*. (1985) describe the weight variation as a consequence of lactation and gestation. Based on lactation functions from Wood (1967) and Wood (1977) the model calculates the production of milk for each cow on each day.

With the daily information on weight, milk production and composition, the daily feed requirements are calculated based on Jarrige *et al.* (1988) and CVB (1996). The requirements and the supply of protein are expressed as Darm Verteerbaar Eiwit (DVE): the true protein digested in the small intestine. In addition, the Onbestendige Eiwit Balans (OEB) value (the ruminally degraded protein, RDP, balance) indicates the losses of N in the rumen. An OEB value above zero indicates a surplus of RDP relative to energy, which means that there is a potential loss of N. If the OEB value is below zero, there is a shortage of RDP relative to energy, which means that microbial protein synthesis is possibly impaired (Kuipers *et al.*, 1999).

The daily requirements of energy are expressed as Voeder Eenheid Melk (VEM) or Feed Unity Milk. The Unité encombrement bovine (UEB) value indicates the maximum volume feed intake capacity of the cows.

The roughage ration in the model is based on the available grass and maize and the compound feed ration is simulated through an optimization of the feed balance.

At the start of the simulation, the user specifies the total area and the crops that are cultivated. Depending on the selected grazing system, the grazing season is simulated in order to fulfil the requirements of the cattle. The excess grass production is mowed and ensiled for the winter period. At the beginning of the winter period the available feedstock determines the ration for the winter. This means that the winter roughage ration can be changed in the model in two ways. The first way is to simulate a different summer situation. Selecting a grazing system with more maize feeding during the summer period results in lower maize and more ensiled grass availability for the winter period. The second way to change the winter ration is changing the share of the crops cultivated. This modelling approach represents the actual decision making process of farmers. At the beginning of the season, a farmer decides the feed crop plan for the next year. Depending on the yields, he can adjust the ration for the cows in order to minimize roughage surpluses at the end of the year.

To balance the feed requirements, the daily amount of compound feed is simulated through a linear programming optimisation for each day. A least cost composition fulfilling the energy and protein requirements is determined for each cow based on the assumption that a farmer is able to compose a cow dependent compound mixture. This is actually representing the situation when a feeding computer is used.

The compound feed plays two roles. It can on the one hand, supply additional energy and on the other hand, correct the protein content and OEB balance. The optimisation of the compound feed module can be represented as follows:

$$\text{Minimize } \sum_i \text{compound\_input}_i * \text{compound\_price}_i$$

Subject to

$$\sum_i \text{compound\_input}_i * \text{OEBcontent}_i \geq 0 - \text{OEB}_{roughage}$$

$$\sum_i \text{compound\_input}_i * \text{VEMcontent}_i \geq \text{VEM}_{needed} - \text{VEM}_{roughage}$$

$$\sum_i \text{compound\_input}_i * \text{DVEcontent}_i \geq \text{DVE}_{needed} - \text{DVE}_{roughage}$$

where:

i is the index of 6 types of compound feed.

2.3.2 Grazing strategy

The grassland production is based on nitrogen-grassland relations described by Thornley and Johnson (1990) and a rotational grazing strategy with the number of rotation days as external variable.

$$\frac{dW}{dt} = RGR_{\max} W - \frac{RGR_{\max} W^2}{W_{\max}} \quad (24)$$

where W is the grass yield (kg ha^{-1}) and RGR_{max} is the maximum relative growth per day, W_{max} is the maximum attainable grass yield, and t is the time. After transformation of RGR_{max} and substituting t_{maxGR}, the day that the maximum growth rate is reached, by a quadratic function of t_{start} and the N-input, to capture the influence of the starting date of the growing season and the N-fertilisation, the following non-linear algebraic expression is obtained from the original differential equation:

$$W = \frac{4\left(C_1 + C_2 N + C_3 N^2\right)}{\left(C_4 + C_5 t_{START} + C_6 t_{START}^2\right)} \left(\frac{1}{1 + e^{\left(C_4 + C_5 t_{START} + C_6 t_{START}^2\right)\left(\left(C_7 + C_8 t_{START} + C_9 t_{START}^2\right) - t\right)}} \right) \quad (25)$$

in which C_1 - C_9 are coefficients fitted to the data, t_{start} the day the growing season starts, N the units of applied nitrogen in kg and t the observed calendar day. The model has been fitted on the basis of experimental data obtained from Behaeghe (1979) and Asijee (1993) for normal growth conditions and from Nevens and Reheul (1998) for the grass growth under management constraints. The resulting model permits to simulate the daily grass growth under Flemish weather conditions in function of the N-fertilisation, the N-application date, the mowing date and a possible delay in the growth due to seasonal and other factors.

The parcel size for the rotational management is simulated from the grass requirement of the cattle on the first grazing day. Based on herd size, the model calculates what parcel size is necessary to graze the herd during the number of days of the selected grass rotation strategy.

The grassland requirement depends on the feeding strategy. The user of the model can choose between feeding a fixed amount of maize, maximization of grass feeding or time dependent maize feeding. In the latter the user can define a starting quantity and a final quantity of maize input. The model then calculates a linear daily increase of maize feeding.

Grassland production that is not used for grazing is mowed. Because the number of mowing cuts has an influence on the total yield of the grassland (Verbruggen, 2000), the model optimises the mowing regime to achieve maximum yield. As the grass yield is a non-linear function of time and N-gift, the mowing regime is optimised with the Praxis-algorithm (Brent 1973) that supports non-linear optimisation.

2.3.3 Nutrient cycling aspects

The nutrient balance of a farm is the difference between the nutrient inputs and nutrient outputs at farm level. The most important inputs bought by the farmer are fertilizers, compound feed and, in case of shortage, extra forage. At the output side the nutrient content of milk, meat and potential surplus of forage are accounted for. N deposition is not considered because this is constant over all scenarios and has thus no influence on the conclusions.

The amount of compound fertilizer needed is calculated as the difference between the need of soil N and P of the crops and the amount applied through available manure. The amount of N and P in the manure is calculated as the difference between the cow's intake of N and P and its output, both at cow level. The calculated amount of N is multiplied by a efficiency factor and a summer and winter manure coefficient of 20% and 80% respectively. The efficiency factor (z) indicates that 1/z kg N in manure is necessary to replace 1 kg N in compound fertilizer for the same yield. Schils and Snijders (1988) report a efficiency factor of 56%. The summer and winter manure coefficients take into account that only a part of the N excreted by the animals is finally available for spreading on the land. In the winter there are mainly storage losses. During the summer only a part of the faeces and urine is captured as manure in the stable. The largest part is disposed directly on the land by the cows. Standard the programme applies a summer and winter manure coefficient of 20% and 80% respectively.

Because other studies indicate that in practice there is a very large variation of these coefficients, the results section contains a sensitivity analysis of these values. Schreuder *et al.* (1995), for instance, do not take the N surplus during summer into account. Nevens and Reheul (1998) found that the short-term fertilization effect of N in manure is only 15% while the long-term effect is 60%. Lewis *et al.* (2002) have shown that the effect strongly depends on the application date and form of the manure.

2.4 Validation

The model results are compared with recent data of farms participating in a nutrient balance-monitoring project (Table 4) (Mulier *et al.*, 2003). These farms do not reflect average results of Flemish dairy farms, because they are encouraged to decrease nutrient surpluses.

Because the simulation model feeds the cows exactly what they need, it is expected that the simulated nutrient surpluses are lower than the observed farm data. Table 5 shows that this is not always the case, probably because some of the observed farms do better for certain parameters than the assumptions for these parameters in the model, because they use storing and spreading techniques resulting in a higher efficiency factor of manure than the average level of 56% assumed.

Also the collected data contain a lot of variations. Mulier *et al.* (2003) indicate four major restrictions to the accurate calculation of farm level nutrient balances: (1) the wide variability that is allowed between actual and reported nutrient composition of concentrated feed; (2) the estimates of the amount and composition of manure; (3) the assessment of changes in standing stock on the farm between the beginning and end of the reporting period and (4) the accuracy of the data supplied by the farmers.

From the large variation between computed and observed values two possible conclusions can be derived. A first possible conclusion is that the model is not capable of reproducing baseline conditions and should not be used. A second possible conclusion is that the observed data are very much influenced by external factors such as weather conditions and measurement errors. A simulation model capable of doing analysis without the influence of these external factors is then the only possible approach to make conclusions about the influence of management decisions on the nutrient surplus at farm level. Because the model is based on different extensively tested and validated functions described in literature, this second conclusion is retained.

Table 4. Farm characteristics included in the model.

Farm characteristics	Farm 1	Farm 2	Farm 3	Farm4
Number of cows	52	71	115	85
Milk production (l per cow / year)	7850	8218	6891	8703
Maize (ha)	19	16	36	33
Grassland (ha)	18	14	36	21

Table 5. Comparison of observed and simulated farm data.

Validation results	Farm 1		Farm 2		Farm 3		Farm4	
	computed	observed	computed	observed	computed	observed	computed	observed
N in sold products (10^3 kg)	3,9	4,1	2,2	3,4	5,2	4,9	6,0	6,1
N in compound feed (10^3 kg)	3,0	2,5	6,0	4,9	8,3	9,6	6,8	9,3
N in fertilizer (10^3 kg)	7,0	8,3	3,1	2,9	10,8	22,1	7,7	9,6
N in forage (10^3 kg)	0,0	0,0	1,1	1,1	0,0	0,0	0,0	0,0
N surplus (10^2 kg/ha)	1,6	1,2	2,3	1,6	1,9	2,6	1,6	1,6

2.5 Simulation results

As indicated, the model is used to simulate the influence of management decisions on the nitrogen surplus. Simulations are done for a farm with the following characteristics:

- 40 Cows
- A production of 7000 kg of milk per cow in the first lactation and 8000 kg per cow from the second lactation on.
- The grazing season starts April 27th and runs until October 2nd (this is an average season under Flemish conditions).

Because calving dates influence the age, weight and feed ration of the calves in a one-year simulation period, young stock is not simulated for this application. This facilitates the comparisons between different simulation scenarios.

The period between two calving dates is assumed to be one year. Three farm systems have been simulated. In the winter milk farm system, cows are calving in October while in the summer milk farm system the calving date is the first of April. In addition a zero grazing farm system has been simulated, with a calving date the first of April.

The acreage of the farm systems is 19 ha for the summer and winter milk farm systems. The zero grazing farm system needs less land to be self-sufficient in fodder crops and has therefore only 17 ha of land.

For these three farm systems results are simulated for different summer rations and varying grass – maize ratios. They are described in the next two sections. Afterwards a comparison is made between the three farm systems and results are tested for sensitivity on fertilizer application rates and the summer and winter manure coefficients.

2.5.1 Influence of the summer ration

To analyse the effects on the N-surplus of maize input during the grazing period, different levels of maize feeding during the summer period are simulated. Figure 7 gives the results for the summer milk and winter milk farm systems for three different levels of maize feeding. The results indicate that the winter milk farm system and a higher maize input during the summer lower the N-surplus. The fertilizer application rates for this simulation are 300 kg N/ha for grassland and 200 kg N/ha for maize.

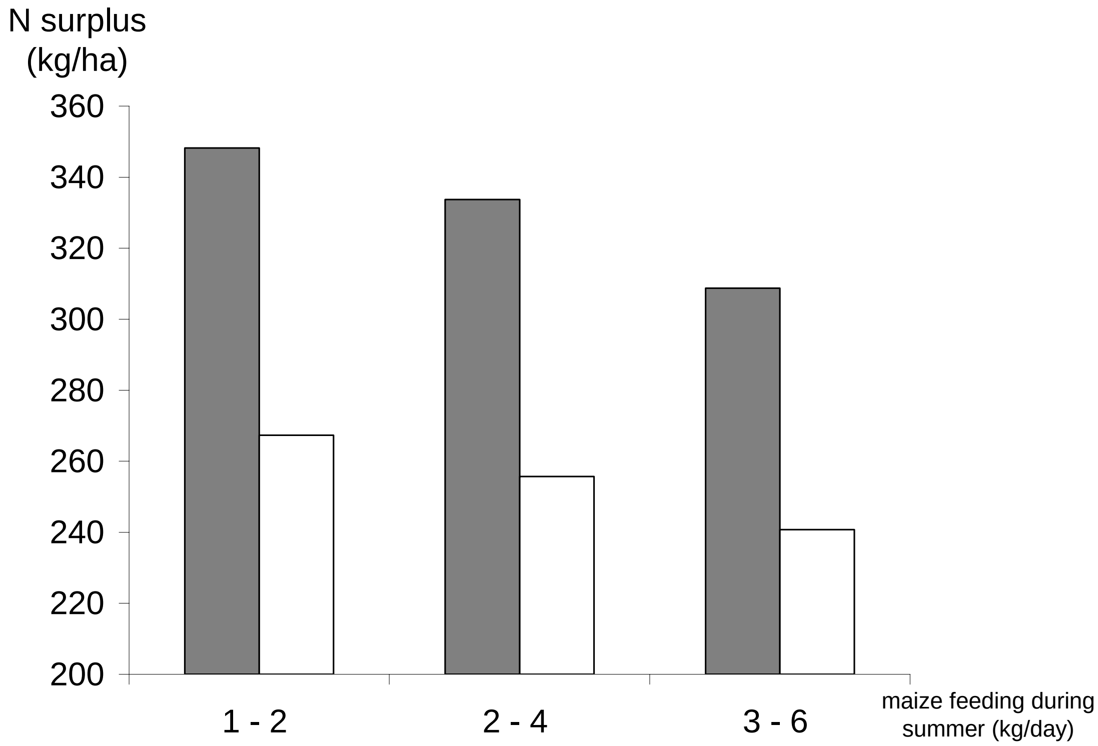

Figure 7. Influence of the summer ration on the N – surplus of the ■ summer milk farm system and the □ winter milk farm system

Different reasons explain these results. A first reason is that more maize during summer and more milk production during winter result in less grazing. As grazing is less efficient than mowing with equal amount of N-fertilization, this results in a lower N-surplus for the wintermilk farm system. Secondly, mowing gives a more N-rich winter feed resulting in better N-recycling, as can be derived from the difference between the winter (80%) and summer (20%) manure coefficient. Thus, the N-surplus at cow level is 60% better recycled during winter than during summer. Another reason is the OEB - balance. Grazing without maize feeding results in a surplus of RDP relative to energy and a positive OEB - balance. A positive OEB - balance indicates that more N - losses occur. Because maize contains more energy relative to RDP, higher maize feeding can lower the OEB - balance, resulting in lower N - losses.

The higher efficiency of mowing compared to grazing has also several reasons. Grazing is done at 1700 – 2200 kg DM (dry matter) / ha while for mowing this is 2500 – 4500 kg DM / ha. Under grazing conditions the grass growth is therefore not reaching its maximum potential, resulting in a lower yield for grazing as illustrated in Figure 8.

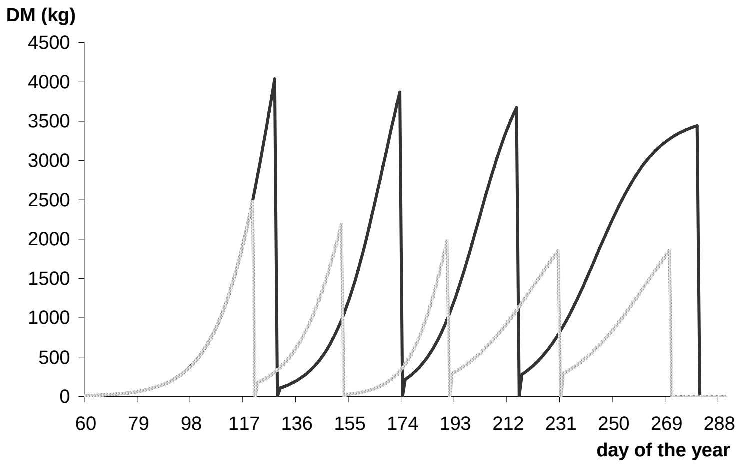

Figure 8. Growth curve of grass under the mowing ▬ and grazing ▬ regime

Another, but less important reason, for the lower efficiency of grazing is the need for permanent supply, in the model achieved by rotational grazing. A consequence of rotational grazing is that at the beginning of the grazing season the cows graze the first parcel before the optimal yield and the last parcel is grazed beyond the optimal yield. In the last grazing cycle the first parcel is grazed three weeks before the end of the grazing season. The grass growth of these three weeks is not used for feeding, resulting in a yield loss. Thus, grazing instead of mowing results in sub-optimal use of overall grass supply at the beginning and at the end of the grazing season. Disadvantages of mowing are the silage losses and the extra labour requirement for mowing and ensiling the grass. This, however, has less impact on the N – balance.

2.5.2 Influence of the grassland - maize ratio

At N - fertilizer application rates of 300 kg/ha grassland and 200 kg/ha maize, maize feeding has a better influence than feeding grass on the N – balance of a dairy farm. This is illustrated in Figure 9. There are two important reasons for this. Forage maize lowers the OEB - balance and maize needs less N – fertilizer for higher energy content. Further, the same arguments as those used for the extra maize content in the summer ration hold here as well (see section 2.5.1).

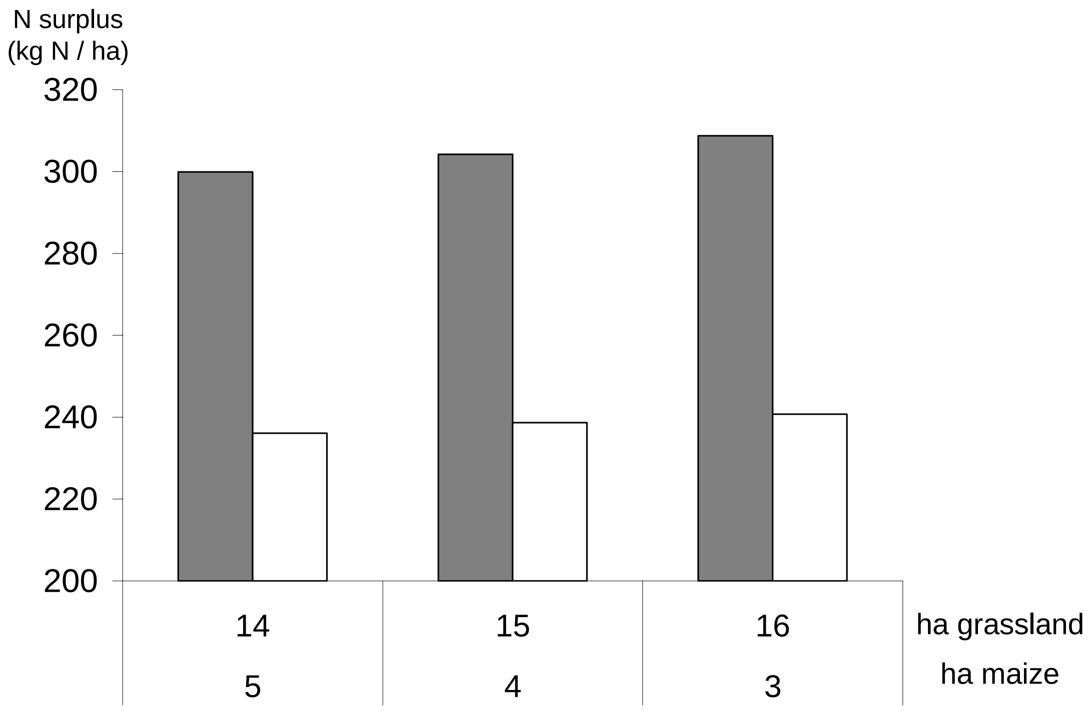

Figure 9. Influence of the grassland – maize ratio on the N – surplus (kg / ha) for the summer milk farm system (■) and the winter milk farm system (□)

Figure 10 shows the results in case of zero grazing. As indicated before, the N – surplus decreases with higher maize areas. The P – surplus, on the other hand increases with more maize production. The first reason is that maize and grassland are equally P - fertilized, but because grassland has a higher protein yield, the P – export is higher. This higher P - use efficiency at field level for grassland than maize is not influenced by the efficiency at cow level because the surplus of P at cow level is in the model assumed to be fully recycled on land (Tamminga, 1992) in contrast with N where important losses occur.

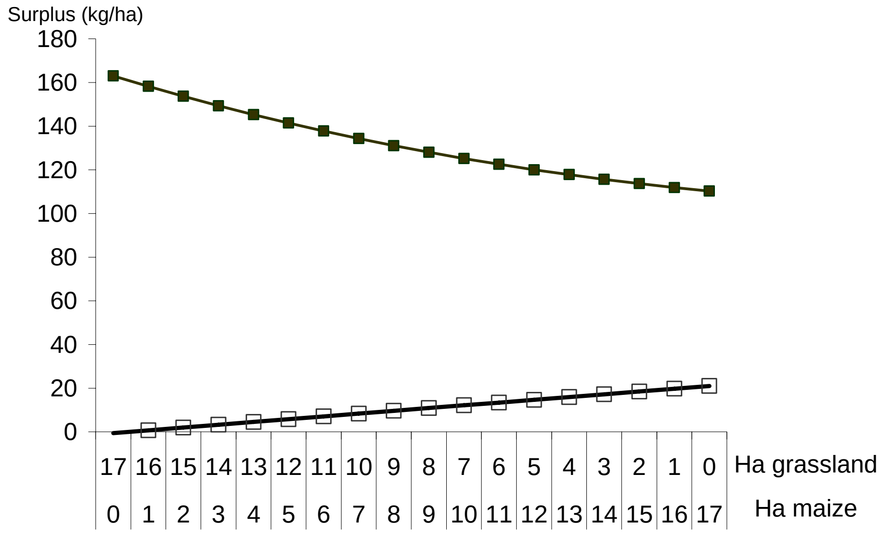

Figure 10. Influence of the grassland – maize ratio on the N – surplus (■) and P - surplus (□) in case of zero grazing.

2.5.3 Summer milk, winter milk and zero grazing.

As can be derived from Figure 11 the annual variation of N – input at cow level is influenced by two major factors. The first and most important is the lactation curve. Two months after calving the milk production and daily N – input reaches a maximum.

The second factor is the grazing period. Both in the winter milk farm system and summer milk farm system a sharp increase in N – input can be observed during the grazing period. The OEB – balance with young grass is too high, resulting in high excretion of N. The manure produced by cows during the stable period is also better recycled than manure produced during a grazing period. This explains the big difference in total surplus between Figure 9 and Figure 10. It may therefore be concluded that zero grazing has a positive effect on the nutrient balance of a dairy farm. Further, farms with grazing have higher nutrient use efficiency the more winter milk they produce.

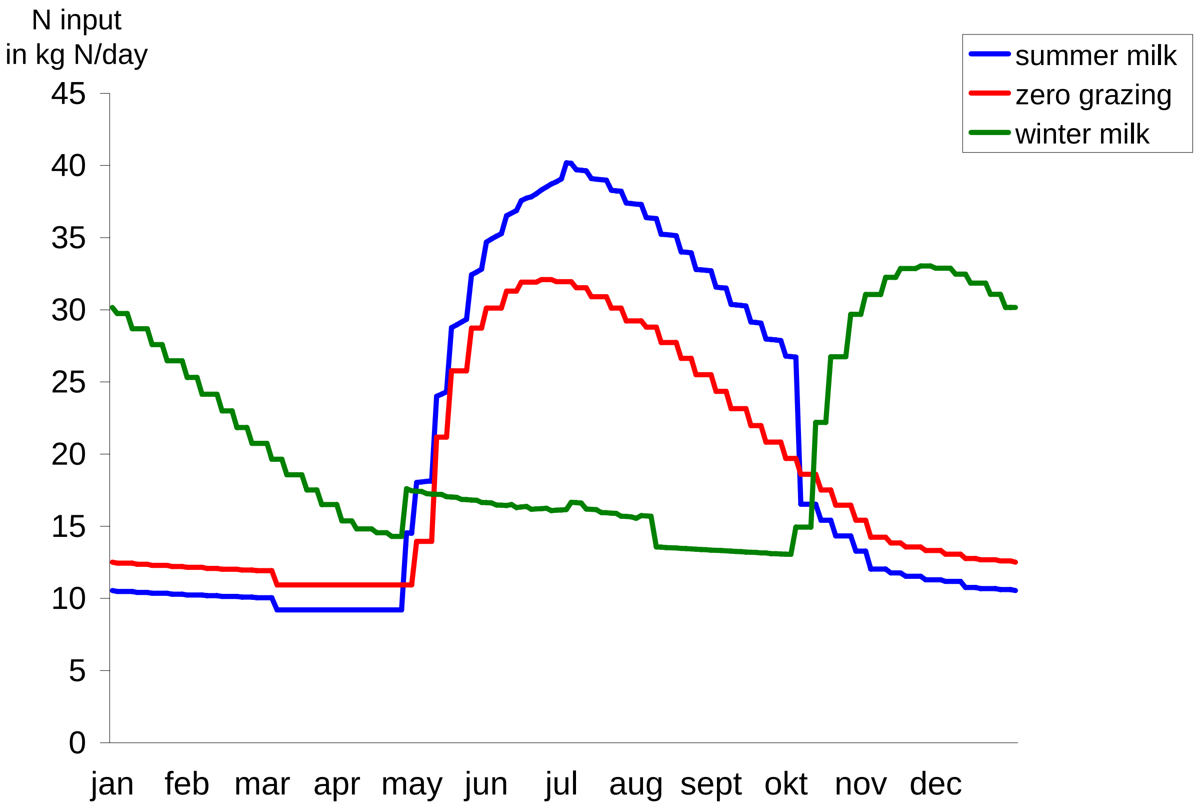

Figure 11. Annual variation of N – input for the whole herd on the summer milk, zero grazing and the winter milk farm systems.

2.6 Sensitivity analysis

A sensitivity analysis has been performed to analyse the influence of fertilizer application rates and the summer and winter manure coefficients on the above results and conclusions.

The simulation results in Figure 12 illustrate the positive effect of reduced N – fertilisation on the N – surplus of a dairy farm. Figure 12 shows a similar effect for the three farm systems modelled. This means that the level of N – fertilization does not change the conclusions of the previous sections for the different farm systems. Zero grazing appears to be the best option for optimal nutrient management, independent whether 200 kg N/ha or 400 kg N/ha fertilization is used.

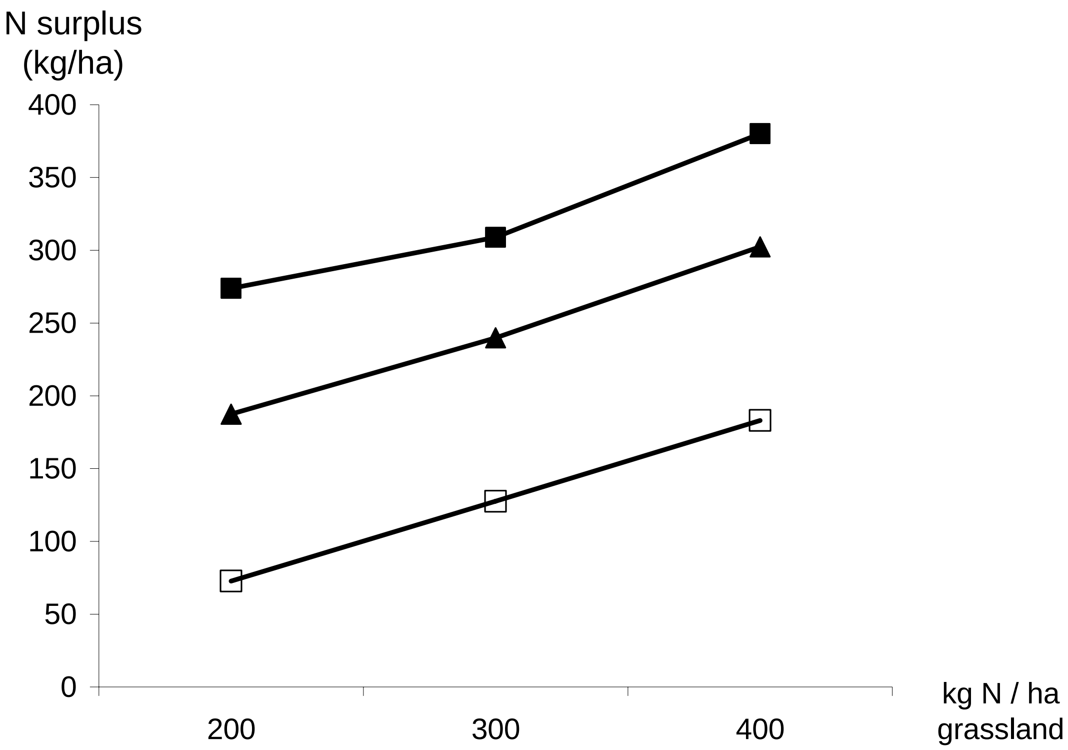

Figure 12. N – surplus with three N – fertilization levels for the summer milk (■), winter milk (▲) and zero grazing (□) farm systems.

For maize feeding the conclusion is different. The benefit on the N surplus of feeding maize decreases with decreasing fertilizer levels. This can be seen by comparing the N - surplus in Figure 10 (300 kg N/ha) and the N - surplus in Figure 13 (200 kg N/ha). For a high fertilisation level, 100% maize gives the lowest N - surplus (Figure 10). For a lower fertilisation level (Figure 13) the N - surplus is lower with a grass - maize mixture than with 100% maize.

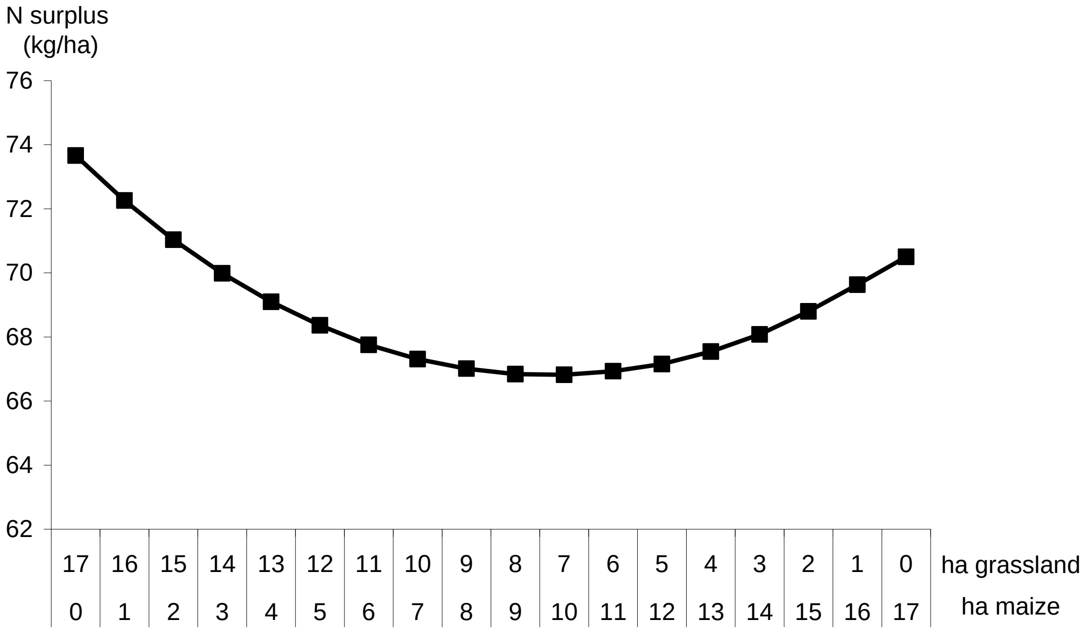

Figure 13. N – surplus for the zero grazing farm system with fertilisation of 200 kg N/ha on grassland and 140 kg N/ha on maize.

The results of the sensitivity analysis of the summer and winter manure coefficients are illustrated in Figure 14. The main conclusion remains valid even with very different summer and winter manure coefficients. The N - surplus of a winter milk farm system is lower than the surplus of a summer milk farm system even if the same manure coefficient for summer and winter is assumed. The higher the difference between both coefficients, the higher the difference in N - surplus in both farm systems becomes.

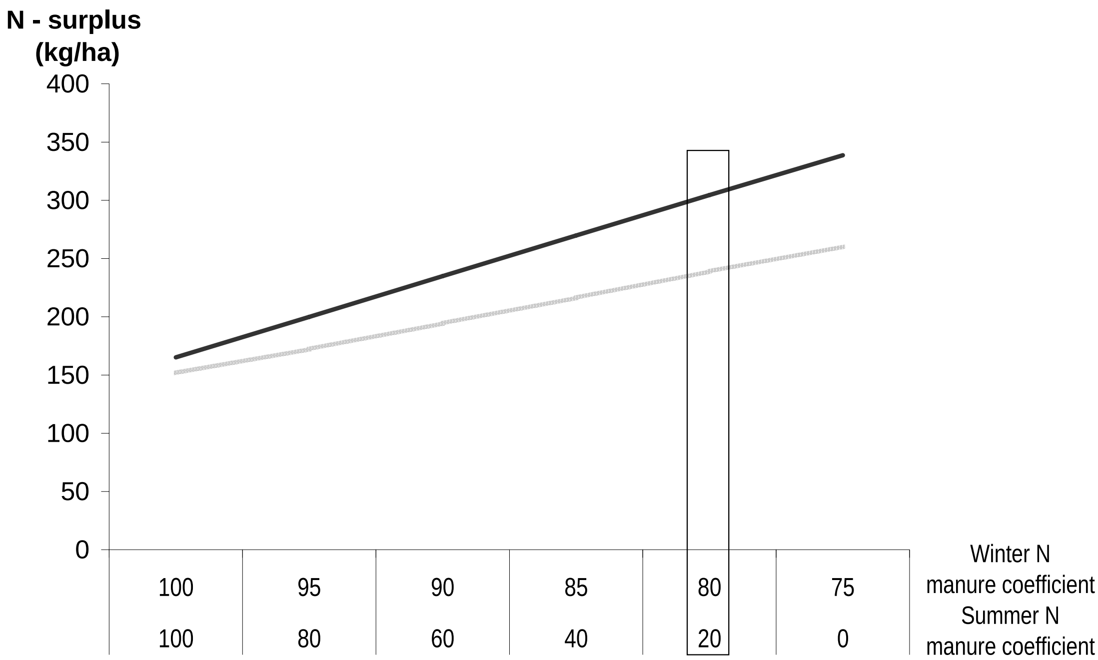

Figure 14. N – surplus for the summer milk (▬) and the winter milk (▬) farm system with varying summer and winter N coefficients.

2.7 Discussion

The model confirms the results of other studies (Jarvis *et al.*, 1996, Michiels *et al.*, 1998, Vermeltfoort *et al.*, 2001) by indicating the positive effects of supplementing grazing with maize feeding on the N - surplus. These results have important implications for policy measures in Flanders and The Netherlands. The Flemish and Dutch governments have asked a derogation from the Nitrate Directive of the European Union for grassland, allowing higher organic fertilizer applications on grassland than on other crops. This can be justified from an agronomic viewpoint as grass is able to utilize the higher fertilisation levels more efficiently than other crops. However, at cow level grassland is not always the best option for a low N - surplus. A derogation for grassland could stimulate Dutch and Flemish farmers to cultivate more grass instead of maize or other fodder crops. This would lead to an overall lower nutrient use efficiency on the dairy farms with high fertiliser application rates. Van Bruchem *et al.* (1999) report that more maize in the feed ration also results in a higher quality of the manure produced by the cattle. As this is not simulated in the model, the positive effects of maize could be even larger than simulated.

From a nutrient use efficiency perspective our model shows that zero grazing is the best option. Vermeltfoort *et al.* (2001) come to a similar conclusion with a statistical comparison of nutrient balances of different farms in the Netherlands. In practice, an increasing number of dairy farmers (in particular in the Netherlands) already applies zero grazing.

However, besides nutrient use efficiency, also labour income is an important consequence of management decisions. It could be expected that zero grazing results in a higher cost. With the present model this could not be assessed (although the model contains an economic calculation) because these costs depend too much on characteristics of the farm structure, such as the system of milking installation and acreage of pasture near the farm, which are not included in the model so far. Other research indicates different effects of zero grazing on labour income. Overvest and Laeven-Kloosterman (1984) and Coléno and Duru (1999) suggest a negative impact of zero grazing on the labour income of the farmer. On the contrary a statistical analysis of 54 specialized dairy farms in the Netherlands showed that less grazing has no negative impact on farm income. Bondt *et al.* (2001) state that farm income and grazing are not directly linked. Larger scale farms with automated milking and limited available land could benefit from zero grazing while smaller farms with more land could be better off with grazing.

Van der Schans (2000) evaluates other side effects of zero grazing. He suggests a negative impact on nature, wildlife, public perception of the dairy sector, countryside and animal welfare. As a reaction CONO (a Dutch cheese factory) has already decided to give a price premium of 1 eurocent per kg milk for farmers that apply grazing.

2.8 Conclusions

2.8.1 Conclusions with respect to the application

In general, the analysis has illustrated the potential of the developed model for quantitatively evaluating the impact of management decisions on the nutrient balance of a dairy farm. The advantage of using models is the possibility of combining separately known functions in one simulation in order to draw conclusions not only at field or at cow level, but also at overall farm level. Further, external parameters influencing observed nutrient balances such as weather conditions and measurements errors can be eliminated, so that the exact influence of practices and systems can be evaluated. As illustrated, the model can be used to evaluate either management options at farm level, but also the effect of possible policy options. Introducing a number of economic and environmental indicators such as ammonia emission, labour income, financial performance indicators and so on could extend the application range of the model as e.g. in the models described by Herrero *et al.* (1999), Ramsden *et al.* (1999) and van Calker *et al.* (2004). This will, however, require additional input parameters as well.

2.8.2 Modelling lessons

The application shows that the farm-level NMP approach allows for a detailed descriptive analysis of a dairy farm. Through the use of the list of input parameters, it is possible to analyse different farm structures with the same model. The application indicates that NMP models can be powerful tools for policy analysis and lead to useful policy recommendations.

The dairy farm model, and in general most farm-level NMP models, can also be used as an advisory instrument for farmers as it can produce as, e.g., in this case a grazing and mowing calendar or it can give more insight into the nutrient balance of the farm.

The validation of the model illustrates, however, one of the main problems of NMP, which was also expressed by one of the reviewers of Agricultural Systems: “My main difficulty with this paper is the model’s inability to simulate baseline conditions. This seems to result from the use of LP to produce optimum conditions that do not prevail on farms. As a result, I do not see how any relevance can be claimed for the intervention scenarios. “

However, the article also explains that exactly this validation problem provides us with two important reasons to choose NMP for the development of such a detailed farm-level model.

First, the problems with the validation data suggest that a modelling exercise is an important approach to separate the general impact of the chosen scenarios from external conditions sometimes linked to farm specific conditions. Other types of assessment of the different scenarios, such as field experiments, are largely influenced by weather, measurement errors, and difficulties in data collection. These data difficulties do not necessarily imply that models should not be built. It is after all better to use good logic (embodied in the model) for policy analysis than to compound the problem of poor data with poor logic (Hazell and Norton, 1986).

Second, the validation also indicates that no data are available with enough details to calibrate the model and turn it into a PMP or EMP model. The calibration could be performed by, e.g., the adjustment of manure efficiency factors. However, to do so, sufficient and accurate data for all other parameters are needed, which are apparently not available yet. Therefore, PMP or EMP could not be applied here.

It should, however, be noted that the model results are only meaningfull if the technology represented in the model correspond to a common technology used by most farmers. The main risk of an NMP model is to produce results with an assumed technology far from the reality, which complicates interpretation and comprehension by researchers and farmers.

Another lesson from this application, which was also raised by the reviewers, is the difference in available knowledge with respect to manure N transactions. The dairy farm model is very detailed on the nutrient transactions from plant level to cow level and from cow level to the product milk and the by-product manure. However, less detail is available on the transformation of manure N to plant production. This lack of detail is due to the limited available knowledge in literature and the wide variety of systems that could be applied. As a consequence, the model relies on simple efficiency factors for manure.

This weakness can be attenuated in NMP models by applying a sensitivity analysis on the efficiency factors. The sensitivity analysis can show to what extent results and conclusions become different for different values of the efficiency factors. The sensitivity analysis is, in general, an important instrument for NMP models.

2.8.3 Other experiences from the dairy farm model

The dairy farm model was originally developed in Matlab and MS Excel. Because of the user unfriendliness and the impossibility to transport the model to a computer without Matlab, it was decided to make a standalone version of the model. The development of the standalone version should result in three advantages:

- the model relies on only one program and should therefore easier be managed;
- the model has a GUI (Graphical User Interface) to facilitate the process of input and management of the data, as well as the process of interpreting results;
- the model can be deployed on every PC without the need for additional software or licenses.

Despite the advantages of a standalone model version programmed in Delphi, there are also three important disadvantages.

The most important disadvantage is that Delphi has less mathematical features than specialised programming languages from modelling packages such as Matlab (http://www.mathworks.com/), GAMS (General Algebraic Modelling System: http://www.gams.com) or AMPL (Algebraic Mathematical Programming Language: http://www.ampl.com).

In Delphi, it is also more difficult to rely on solvers for the optimisation of a problem, while, e.g., GAMS has a standard link with a set of more than 10 different solvers. This second disadvantage could also be an advantage, because the optimisation algorithm could specifically be developed for the problem in the model. However, we had not sufficient knowledge and time to do so. Therefore, the optimisation algorithm from Brent (1973) applied in the model is probably far less powerful than, e.g., the nonlinear solvers available in GAMS.

The third disadvantage is that the development of a standalone version is rather time-consuming.

Chapter 3 Positive Mathematical Programming: introduction to the farm-level calibrated model SEPALE

Positive mathematical programming (PMP) has renewed the interest in mathematical modeling of agricultural and environmental policies. Before going into detail on PMP, this chapter starts in the introduction with a short literature review of the concept 'calibration'. This chapter explains and discusses first the original PMP approach (Howitt, 1995a), followed by a presentation of an individual farm-based sector model, called SEPALE. The farm-based approach allows the introduction of differences in individual farm structures in the PMP modeling framework. Furthermore, a farm-level model gives the possibility of identifying the impacts according to various farm characteristics. Simulations of possible alternatives to the implementation of the CAP Mid Term Reform illustrate the model.

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3.1 Introduction

Chapter 1 has already explained that calibration makes the difference between NMP and PMP. Before going further into detail on PMP, we want first to shed some light on the term 'calibration'.

Calibration is sometimes confused with the term validation, which is used in chapter 3. A whole book could be written on the philosophical and practical issues involved in validation (Kleijnen, 2001). In his survey, Kleijnen (2001) defines validation as determining whether the simulation model is an acceptable representation of the real system - given the purpose of the simulation model. Therefore, validation is more a step taken after a model has been developed, while calibration is a step in the actual quantification of the model's parameters.

A literature review illustrates that calibration has evolved differently in different areas of research:

- Calibration is commonly applied to CGE models to make sure that equilibrium conditions are satisfied (Arndt *et al.*, 2002).
- Later calibration appears into macro-economics literature for quantification of real-business-cycle (RBC) models and has now a wide range of applications (Hoover, 1995). In RBC models, calibration refers to the Euler equations, which is the set of first-order conditions of a dynamic system of equations.
- In micro-economic models, calibration was widely practiced, but rarely formally described (Howitt, 1995b). In this case, the modellers use formal or informal calibration methods to match the model outcome to the available data base. Since the formal description of PMP (Howitt, 1995a), calibration in sector level programming models has become a widely applied practice. Calibration in programming models is used to fit the parameters such that the data reflect the optimum in the model.

A common element in the use of calibration in the different fields of research is that empirical data are used to quantify parameters such that the model's outcome reflects, as close as possible, the simulated outcome with the observed data as inputs. This model's outcome can be either an equilibrium (in CGE models) or an optimum of the objective function subject to constraints (in MP models). The differences in calibration come, therefore, mainly from the differences in data, model structure and model outcome.

Due to the wide variety of applications of calibration in economics, there is also diversity in the definition of calibration.

Pagan (1994) calls calibration the methodology reluctant of making assumptions about error terms because they are only treated as what is needed to reconcile the data with the model. Kleijnen (1993) defines calibration as the adjustment of simulation model's parameters (using some minimisation algorithm) such that the simulated output deviates minimally from the real output. Brown and Oman (1991) state that in calibration problems one wishes to predict a quantity whose precise measurement is difficult or expensive to obtain by a less precise but more easily obtained measurement.

This definition of Brown and Oman (1991) is probably true for all calibrated mathematical programming models, since calibration would be useless if all driving factors and all constraints of a problem were known. Calibration in the context or programming models could therefore be considered as a simplification of the model and modelling process.

However, we prefer to use the definition of calibration in PMP provided by Hoover (1995) and in which we replace 'or' by 'and': *"A model is calibrated when its parameters are quantified from casual empiricism or unrelated econometric studies and are chosen to guarantee that the model precisely mimics some particular feature of the historical data."*

The definition of Kleijnen (1993) is more applicable to the type of calibration that is described in EMP models (see Chapter 5).

3.2 The original PMP Approach

PMP, as formalised by Howitt (1995a), is a method to calibrate mathematical programming models to observed behaviour during a baseline by using the information provided by the dual variables of calibration constraints. The dual information related the vector of the observed activity levels is used to calibrate a nonlinear objective function such that the observed activity levels are reproduced for the baseline but without the calibration constraints. The term "positive" that qualifies this method implies that the parameters of the non-linear objective function are derived from an economic behaviour assumed to be rational given all the observed and non-observed conditions that generates the observed activity levels.

PMP, as formalised by Howitt (1995a), follows a procedure in three steps. The first step consists in writing an MP model as usual but adding to the set of limiting resource constraints a set of calibration constraints that bound the activities to the observed levels of the baseline. Taking the case of maximising gross margins with upper bounded calibration constraints, we write the initial model as in Paris and Howitt (1998):

$$\text{Maximise } Z = \mathbf{p}'\,\mathbf{x} - \mathbf{c}'\,\mathbf{x} \tag{26}$$

subject to:

$$\mathbf{A}\,\mathbf{x} \leq \mathbf{b} \qquad [\lambda] \tag{27}$$

$$\mathbf{x} \leq \mathbf{x_o} + \boldsymbol{\varepsilon} \qquad [\rho] \tag{28}$$

$$\mathbf{x} \geq 0 \tag{29}$$

where:

- Z scalar of the objective function value,
- **p** (n x 1) vector of product prices,
- **x** (n x 1) non-negative vector of production activity levels,
- **c** (n x 1) vector of accounting costs per unit of activity,
- **A** (m x n) matrix of coefficients in resource constraints,
- **b** (m x 1) vector of available resource levels,
- $\mathbf{x_o}$ (n x 1) non-negative vector of observed activity levels,
- $\boldsymbol{\varepsilon}$ (n x 1) vector of small positive numbers for preventing linear dependency between the structural constraints and the calibration constraints,
- λ (m x 1) vector of duals associated with the allocable resource constraints,
- ρ (n x 1) vector of duals associated with the calibration constraints.

Assuming that all activity levels are strictly positive and all allocable resource constraints are binding at the optimal solution, the first-order conditions of model (26) provide the following dual values as in Heckelei and Wolff (2003):

$$\rho^p = \mathbf{p^p} - \mathbf{c^p} - \mathbf{A^{p'}}\,\lambda \tag{30}$$

$$\rho^m = \mathbf{p^m} - \mathbf{c^m} - \mathbf{A^{m'}}\,\lambda = \mathbf{0} \tag{31}$$

$$\lambda = (\mathbf{A^{m'}})^{-1}\,(\mathbf{p^m} - \mathbf{c^m}) \tag{32}$$

The vector $\mathbf{x}$ is partitioned into [(n – m) x 1] vector of preferable activities $\mathbf{x^p}$ constrained by the calibration constraints (1b) and (m x 1) vector of marginal activities $\mathbf{x^m}$ constrained by the allocable resource constraints (1a). The other vectors ρ, $\mathbf{p}$ and $\mathbf{c}$ and the matrix $\mathbf{A}$ are partitioned accordingly.

Howitt (1995a) and Paris and Howitt (1998) interpret the dual variable vector ρ associated with the calibration constraints as capturing any type of model mis-specification, data errors, aggregate bias, risk behaviour and price expectations. In the perspective of calibrating a non-linear decreasing yield function as in Howitt (1995a), this dual vector ρ represents the difference between the activity average and marginal value products. In the alternative perspective of calibrating a non-linear increasing cost function as in Paris and Howitt (1998), this dual vector ρ is interpreted as a differential marginal cost vector that together with the activity accounting cost vector $\mathbf{c}$ reveals the actual variable marginal cost of supplying the observed activity vector $\mathbf{x_o}$.

The second step of PMP consists in using these duals to calibrate the parameters of the non-linear objective function. A usual case considers calibrating the parameters of a variable cost function C^v that has the typical multi-output quadratic functional form, however, holding constant variable input prices at the observed market level as follows:

$$C^v(\mathbf{x}) = \mathbf{d}'\,\mathbf{x} + \mathbf{x}'\,\mathbf{Q}\,\mathbf{x} / 2 \tag{33}$$

where:

d (n x 1) vector of parameters of the cost function,

Q (n x n) symmetric, positive (semi-) definite matrix with typical element $q_{ii'}$ for activities i and i'.

Other functional forms are possible. The constant elasticity of substitution (CES) production function (Howitt, 1995b) in addition to the constant elasticity of transformation production function (Graindorge *et al.*, 2001) have also been used.

At this point, Heckelei (2002) describes a conceptual shortcoming of PMP: the limited rationalisation of the nonlinear terms in the model. These non-linear terms are often not motivated by behavioural or technological assumptions but rather with determinants of supply behaviour not captured by the other elements of the model. Heckelei (2002) describes four different types of rationalisation of these nonlinear terms: heterogenous land quality, unknown resource constraints, convex combination constraints to mitigate aggregation errors or risk aversion behaviour to price uncertainty.

The variable marginal cost vector $\mathbf{MC}^v$ of the typical quadratic cost function is set equal to the sum of the accounting cost vector **c** and the differential marginal cost vector ρ as follows:

$$\mathbf{MC}^v = \nabla C^v(\mathbf{x})_{\mathbf{x_o}}' = \mathbf{d} + \mathbf{Q}\,\mathbf{x_o} = \mathbf{c} + \rho \qquad (34)$$

where:

$\nabla C^v(\mathbf{x})$ is a (1 x n) gradient vector of first derivatives of $C^v(\mathbf{x})$ for $\mathbf{x = x_o}$.

To solve this system of *n* equations for $[n + n(n + 1)/2]$ parameters and, thus, overcome the under-determination of the system, PMP modellers rely on various solutions.

A first, *ad hoc* solution consists in assuming that the symmetric matrix **Q** is diagonal, implying that the change in the actual marginal cost of activity *i* with respect to the level of activity *i'* ($i \neq i'$) is null and, then, in relying on additional assumptions. Common additional assumptions consist in posing the vector **d** of the quadratic cost function to be either equal to zero, which leads to:

$$q_{ii} = (c_i + \rho_i)/\, x_{io} \text{ and } d_i = 0 \text{ for all } i = 1, \ldots n,$$

or equal to the accounting cost vector **c**, which leads to:

$$q_{ii} = \rho_i / x_{io} \text{ and } d_i = c_i \text{ for all } i = 1, \ldots n.$$

Another calibration rule called the average cost approach equates the accounting cost vector **c** to the average cost vector of the quadratic cost function, which leads to:

$$q_{ii} = 2\, \rho_i / x_{io} \text{ and } d_i = c_i - \rho_i \text{ for all } i = 1, \ldots n.$$

Exogenous supply elasticities ε_{ii} are also used to derive the parameters of the quadratic cost function as in Helming *et al.* (2001):

$$q_{ii} = p_{io} / \varepsilon_{ii}\, x_{io} \text{ and } d_i = c_i + \rho_i - q_{ii}\, x_{io} \text{ for all } i = 1, \ldots n.$$

All these specifications would exactly calibrate the initial model as long as equation (34) is verified, but lead to different simulation responses to external changes.

A subsequent development from Paris and Howitt (1998) to calibrate the marginal cost function is to exploit the maximum entropy estimator to determine all the $[n + n(n + 1)/2]$ elements of the vector **d** and matrix **Q** using the Cholesky factorisation of this matrix **Q** to guarantee that the calibrated matrix **Q** is actually symmetric positive semi-definite.[5] This estimator in combination with PMP enables to calibrate a quadratic variable cost function accommodating complementarity and competitiveness among activities still based on a single observation but using *a priori* information on support bounds. Nevertheless, as argued in Heckelei and Britz (2000), the simulation behaviours of the resulting calibrated model would be still arbitrary because heavily dominated by the supports.

Heckelei and Britz (2000) exploit the suggestion from Paris and Howitt (1998) to use the maximum entropy estimator to determine these parameters on the basis of additional observations of the same farm or region in a view to collect information on second order derivatives. They estimate the parameters of the vector **d** and matrix **Q** on the basis of cross sectional vectors of marginal costs and the use of the Cholesky decomposition of the matrix of the second order derivatives as additional constraints. They obtain a greater successful *ex-post* validation than using the standard "single observation" maximum entropy approach. This cross sectional procedure is an interesting response to the lack of empirical validation for models that are calibrated on a single base year. The method is used to calibrate the cost functions of the regional activity supplies of the Common Agricultural Policy Regional Impact (CAPRI) modelling system (Heckelei and Britz, 2001).

The third step of PMP uses the calibrated non-linear objective function in a non-linear programming problem similar to the original one except for the calibration constraints. This calibrated non-linear model is consistent with the choice of the non-linear activity yield or cost function derived in the preceding step and exactly reproduces observed activity levels and original duals of the limiting resource constraints.

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[5] In short, the maximum entropy approach consists in estimating parameters regarded as expected values of associated probability distributions defined over a set of a priori discrete supports (Golan *et al.*, 1996).

The following PMP model is ready for simulation.

$$\text{Maximise } Z = \mathbf{p}'\,\mathbf{x} - \mathbf{d}'\,\mathbf{x} - \mathbf{x}'\,\mathbf{Q}\,\mathbf{x} / 2 \tag{35}$$

subject to:

$$\mathbf{A}\,\mathbf{x} \leq \mathbf{b} \qquad [\lambda] \tag{36}$$

$$\mathbf{x} \geq \mathbf{0} \tag{37}$$

where the vector **d** and matrix **Q** are the calibrated parameters of the non-linear objective function.

Assuming again that i) all optimal activity levels are strictly positive and ii) allocable resource constraints are all binding at the optimal solution and iii) **Q** is invertible, the first-order conditions of model (35) provide the following dual values of the resource constraints as in Heckelei and Wolff (2003):

$$\lambda = (\mathbf{A}\,\mathbf{Q}^{-1}\,\mathbf{A}')^{-1}\,(\mathbf{A}\,\mathbf{Q}^{-1}\,(\mathbf{p} - \mathbf{d}) - \mathbf{b}) \tag{38}$$

This calibration approach has been applied at the farm, regional and sector levels. When accounting data of a sample of *F* farms are available such as from the FADN, *F* PMP models can be defined for each farm of the sample. Simulations can then be performed on these individual PMP models and simulation results may be aggregated as shown in the application in section 3.5. The fact that this is possible increases the farm level information that such models can yield as will be shown in Chapter 5.

3.3 Discussion of the original PMP Approach

Section 1.3 explains that the basic idea behind the calibration of a programming model is to assign all unknown parameter in such a way that the optimality conditions are satisfied for the empirical data. In most cases, the modeller has not sufficient data and has to rely on assumptions and/or simplifications.

In the original PMP approach (Howitt, 1995a) the assumptions that have to be made are divided in the first two steps of the PMP. The first step of the original PMP approach makes an assumption by assigning the highest possible values to the dual of the resource constraint[6]. The value of ε in equation (28) plays an important role in this assumption. Howitt (1995a) explains that this small number is used to decouple the structural constraints from the calibration constraints. However, depending on the scaling of the original problem different values of ε can return different duals of calibration constraints. Paris (2001) state that if the dual of the resource constraints become zero, ε is too low.

The second step of making assumptions solves the under-determination problem in equation (34). As explained above, PMP modellers rely therefore on various solutions. Some of these solutions try to reduce the use of restrictive assumptions to a minimum by exploiting multiple observations and estimation techniques (Heckelei and Britz, 2001). However, these estimations start with the assumptions made in the first step of PMP and are therefore likely biased.

For that reason, Heckelei and Wolff (2003) recently explain that the original PMP approach is not well suited to the estimation of programming models that use multiple cross-sectional or chronological observations. They show that the derived marginal cost conditions (8) prevent a consistent estimation of the parameters when the ultimate model (7) is seen as representing adequately the true data generating process. Their argument goes as follows. On the one hand, the shadow price value vector λ implied by the ultimate model (7) is determined by the vectors **p**, **d** and **b** and the matrices **A** and **Q** through the first-order condition derived expression (8). On the other hand, the various dual value vectors λ from the sample initial

[6] The dual value of the resource constraints of phase 1 of original PMP is the highest possible if it is assumed that the total cost correspond to the sum of the observed accounting costs used in phase 1 of PMP and some potential unobserved costs. These observed accounting cost define then a minimum for the calibrated total cost function.

Equation (31) and (32) illustrate that the PMP model would then be calibrated for any value of the dual of the resource constraint in the interval [0 - λ]. However, if the value of the dual of the resource constraint would be λ + e (e is a very small positive number), the dual of the calibration constraint of the marginal crop would become negative:

$$\rho^{m} = \mathbf{p}^{m} - \mathbf{c}^{m} - \mathbf{A}^{m\prime}\,[(\mathbf{A}^{m\prime})^{-1}\,(\mathbf{p}^{m} - \mathbf{c}^{m}) + e] = -\,\mathbf{A}^{m\prime}\,e$$

This negative dual for the calibration constraint implies that the model would not be perfectly calibrated anymore because the simulated quantities for the marginal crop would be lower than the observed quantities.

model are solely determined by the vectors **p** and **c** and matrix **A** of only those marginal activities bounded by the resource constraints through the first-order derived expression (4). As a result, the various vectors λ of resource duals of the initial models are most generally different from the vector λ of resource duals of the ultimate model. Since the first step simultaneously sets both the initial dual vectors ρ and λ and the second step uses the initial dual vector ρ to estimate the vector $\mathbf{MC}^v$, this latter vector must generally be inconsistent with the ultimate model. The derived marginal conditions are, therefore, most likely to be biased estimating equations yielding inconsistent parameter estimates.[7]

To avoid inconsistency between steps 1 and 3 as further exposed in Heckelei and Britz (2005), Heckelei and Wolff (2003) suggest to skip the first step altogether and employ directly the optimality conditions of the desired programming model to estimate and calibrate simultaneously shadow prices and parameters. They illustrate this general alternative to the original PMP through three examples relying on the Generalised Maximum Entropy (GME) procedure for estimating the model parameters. Their examples deal with the estimation of the parameters of various optimisation models that (1) incorporate a quadratic cost function and only one constraint on land availability, (2) allocate variable and fixed inputs to production activities represented by activity-specific production functions or (3) allocate fixed inputs to production activities represented by activity-specific profit functions.

3.4 Further PMP developments

While being an appealing method for calibration, PMP has shown shortcomings in model calibration that, in turn, motivated further developments. One of these shortcomings is the missing representation of economic behaviours with regard to activities of farms whose initial observed supply level is zero during the baseline. To overcome this self-selection problem during the calibration as well as during the simulation steps, Paris and Arfini (2000) add to the *F* PMP models a supplementary PMP model for the whole farm sample and calibrate a frontier cost function for all the activities included in the whole farm sample.

A second development of the PMP methodology concerns the integration of risk. For example, Paris (1997) uses a von Neumann-Morgenstern expected utility approach assuming a normal distribution of output prices and a constant absolute risk aversion.

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[7] In other words, the 'estimated' value of the dual vector λ cannot converge to the true dual vector λ as more observations are added because PMP always selects the highest possible value for the dual vector λ.

A third development is the inclusion of greater competitiveness among close competitive activities whose requirements for limiting resources are more similar than with other activities. Rohm and Dabbert (2003) represent these close competitive activities as variant activities from their generic activities and add to the first PMP step calibration constraints for these variant activities that are less restrictive than their counterparts for their generic activities.

A fourth development to overcome criticisms that have been raised against the use of a linear technology in limiting resources and the zero-marginal product for one of the calibrating constraints is the expansion of the PMP framework into a Symmetric Positive Equilibrium Problem (SPEP). Paris (2001) and Paris and Howitt (2001) express the first step of this new structure as an equilibrium problem consisting of symmetric primal and dual constraints and the third step as an equilibrium problem between demand and supply functions of inputs, on the one hand, and between marginal cost and marginal revenue of the output activities, on the other hand. For these authors, the key novelty of this new framework is rendering the availability of limiting inputs responsive to output levels and input price changes. Britz *et al.* (2003), however, address several conceptual concerns with respect to the SPEP methodology and question the economic interpretation of the final model ready for simulations.

3.5 SEPALE: System for evaluation of agro- and agro-environmental policies.

This section illustrates how the PMP concept can be applied within an agricultural model that can be used to simulate various policy scenarios. The agricultural model is composed of a collection of micro-economic mathematical programming models each representing the optimising farmer's behaviour at the farm level. Parameters of each PMP model are calibrated on decision data observed during a baseline exploiting the optimality first-order conditions and the observed opportunity cost of limiting resources. Simulation results can be aggregated according to farm localisation, type and size.

Exploiting the richness of the FADN data, this model is part of an effort initially funded by the Belgian Federal Ministry of Agriculture to develop a decision support system for agricultural and environmental policy analysis. The model is known under the name of SEPALE and is developed by a group of agricultural economists based at the Université Catholique de Louvain, the University of Ghent and the Centre for Agricultural Economics of the Ministry of the Flemish Community. Since this model predominantly uses FADN data, it is conceivably applicable to all the EU-15 58000 representative commercial farms recorded in this database accessible by any national or regional administrative agencies.

Before presenting an application drawn from the June 2003 CAP reform (also called mid-term review of Agenda 2000), the following subsection first presents how key parameters of the model are calibrated in the farm generic model and how animal feeding and quota constraints are added to the generic farm model.

3.5.1 Description of the basic farm model

The model consists of a compilation of individual farm mathematical programming (MP) models following the general calibration approach described in the previous chapters. We derive directly, as also Judez *et al.* (2001) suggest, the unknown parameters of the final non-linear model from the Kuhn-Tucker conditions of such final model considering exclusively the activities whose observed levels are different from zero and the opportunity costs of the limiting resources as given exogenously to the model.

On the premise that farms are able to acquire farmland from other farms, farmland is here supposed to be not a binding resource at the farm level, merely an expensive one, and enter into the variable cost component.[8]

The individual farm model relies on a farm level profit function using the typical simplified quadratic functional form for its cost component. In matrix notation, this gives:

$$Z_f = \mathbf{p_f}' \mathbf{x_f} + \mathbf{a_f}' \mathbf{S_f} \mathbf{x_f} - \mathbf{x_f}' \mathbf{Q_f} \mathbf{x_f} / 2 - \mathbf{d_f}' \mathbf{x_f} \tag{39}$$

with

f indexing the farms from 1 to F,

[8] The reader may verify from model (1) that the quadratic parameter matrix **Q** is invariant to whether keeping the binding constraint on farmland and using the farmland rental cost as a proxy for its shadow value or removing the farmland binding constraint and including the farmland rental cost in the average cost. The linear vector **d** is just inflated by the value of the farmland rental cost in the latter alternative.

where:

$\mathbf{x_f}$ is a (N x 1) column vector of production quantities (indexed by i),

$\mathbf{p_f}$ is a (N x 1) column vector of output prices per unit of production quantity (indexed by i),

$\mathbf{a_f}$ is a (N x 1) column vector of technical coefficients determining how much resource base (i.e., farmland) is needed per unit of production quantity x_{if},

$\mathbf{S_f}$ is a (N x N) diagonal matrix of subsidies per unit of resource base,

$\mathbf{Q_f}$ is a (N x N) diagonal matrix of quadratic cost function parameters,

$\mathbf{d_f}$ is a (N x 1) vector of linear cost function parameters (indexed by i).

Two sets of equations calibrate the parameters of the matrix $\mathbf{Q_f}$ and the vector $\mathbf{d_f}$, relying on the technical coefficients $\mathbf{a_{fo}}$, output quantities $\mathbf{x_{fo}}$, output prices $\mathbf{p_{fo}}$, subsidies $\mathbf{S_{fo}}$ and unit production costs $\mathbf{c_{fo}}$ observed at the baseline.

The first-order conditions of model (39) determine the first set of equations for strictly positive production quantities $\mathbf{x_{fo}}$ as follows:

$$\mathbf{p_{fo}} + \mathbf{S_{fo}}\,\mathbf{a_{fo}} = \mathbf{Q_f}\,\mathbf{x_{fo}} + \mathbf{d_f} \qquad (40)$$

The second set of equations equates the observed average costs $\mathbf{c_{fo}}$ to the average costs implied by model (39) as follows:

$$\mathbf{c_{fo}} = \mathbf{Q_f}\,\mathbf{x_{fo}}/2 + \mathbf{d_f} \qquad (41)$$

with $\mathbf{c_{fo}}$ the (N x 1) column vector of observed costs per unit of production quantity that include costs of seeds, fertilizers, pesticides, contract work and other costs as well as farmland rental cost gathered from the FADN for each farm *f*.

The following two sets of equations calibrate the diagonal matrix $\mathbf{Q_f}$ and the vector $\mathbf{d_f}$ for each farm *f* of the sample as follows:

$$\mathbf{Q_f} = 2\,(\mathbf{i}\,\mathbf{x_{fo}}')^{-1}\,\mathbf{i}\,(\mathbf{p_{fo}} + \mathbf{S_{fo}}\,\mathbf{a_{fo}} - \mathbf{c_{fo}})' \qquad (42)$$

$$\mathbf{d_f} = 2\,\mathbf{c_{fo}} - \mathbf{p_{fo}} - \mathbf{S_{fo}}'\,\mathbf{a_{fo}} \qquad (43)$$

where:

$\mathbf{i}$ is a (N X 1) unit column vector.

With these parameters, the farm model (39) is exactly calibrated to the baseline and is ready for simulation. Simulations simultaneously run the compilation of the F calibrated farm models with the following additional land constraint over the F farms:

$$\sum_{f=1}^{F} \mathbf{a_f}'\mathbf{x_f} = \sum_{f=1}^{F} \mathbf{a_f}'\mathbf{x_{fo}} \qquad (44)$$

As a consequence of the overall land constraint, land is freely exchanged across farms during simulations and allocated to farms that use it most profitably. The model does not distinct between buying and renting for exchanging of land use. The dual of the overall land constraint indicates variations in the land opportunity cost with respect to its initial cost. This dual is zero for the baseline because the cost of land is included in the cost function. Afterwards, individual farm simulation results can be aggregated according to farm localisation, type and size.

The basic model is further extended with feeding and quota constraints. The feeding constraint uses a CES function that allows substitution between on-farm forage crops and off-farm feed that is calibrated on feedings observed at the baseline. The A and B sugar quota constraint is included into the first-order conditions of model (15) by adding to the right side of equation (16) the dual of the sugar beet quota. The gross margin differential between the A and B sugar beets and the next best alternative crop that is observed at the baseline approximates this dual. As explained in Buysse *et al.* (2004), the supply of A and B sugar beets includes a precautionary C supply and a quota exchange mechanism allows for a quota redistribution among sugar beet farms within the sample. Chapter 4 and Chapter 5 provide more details on the precautionary supply function and the quota exchange.

3.5.2 Simulation of the Mid-term Review of Agenda 2000

To illustrate the model, we apply it to assess the effects of the June 2003 CAP reform for a sample of Belgian farms. The three main elements in the Mid-Term Review (MTR) of Agenda 2000 are direct payment decoupling, cross-compliance and modulation. First, the decoupling of direct payments implies that one single farm payment replaces the previous direct payments that were linked to activities. Second, the cross-compliance renders the single farm payment subject to farm compliance with rules related to food safety, animal health and welfare and good agricultural and environmental practices. Third, the modulation introduces a system of a 5% progressive reduction of the direct payments that are higher than a threshold of 5 000 euro per farm[9]. The following subsections show how the basic model is modified to incorporate the provisions of the new MTR policy instruments.

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[9] The savings on these direct payments are added to the financing of the rural development measures defined into the CAP. Within the transitory options offered by the MTR, the Belgian government chooses to decouple all direct payments except payments for suckler cows and veal slaughters.

3.5.2.1 Activation of the single payment entitlement

The MTR assigns a single farm payment entitlement per ha for every farm. This per ha single entitlement is the ratio of the amount of direct payments granted to the farm during a reference period over the farmland declared for requesting the direct payments during the same reference period, including farmland for cereals, oil yielding and protein (COP) and fodder crops, but not including farmland for potatoes, vegetables and sugar beets.

Farmland planted with the eligible crops, i.e., all crops (including fallow) except potatoes and vegetables in open air, can activate the per ha single payment entitlement. Three situations could occur:

1. A farm that utilises an area with eligible crops of the same size of the reference farmland is entitled to receive the same amount of direct payments as before the MTR.

2. A farm that increases its eligible crop area is not entitled to additional direct payments.

3. A farm that reduces its eligible crop area is entitled to lower direct payments than before the MTR.

To model the MTR single farm payment adequately, a set of variables $\mathbf{aa_f}$ is defined to represent the maximum eligible area that can activate the per ha single payment entitlement. A first constraint prevents the total single payment to exceed the reference amount of direct payments. A second constraint restricts the per ha single payment entitlement to the eligible area.

$$aa_f \leq \mathbf{a_{fo}}' \mathbf{S_f} \; \mathbf{x_{fo}} \tag{45}$$

$$aa_f \leq \mathbf{a_f}' \mathbf{E_f} \, \mathbf{x_f} \tag{46}$$

where:

$\mathbf{S_f}$ (N x N) diagonal matrix with unit elements indicating whether the activity j has been declared for obtaining direct payments during the reference period and zero elements for other activities,

$\mathbf{E_f}$ (N x 1) diagonal matrix with unit elements for eligible crops and zero elements for others,

aa_f the maximum eligible area for the per ha single payment entitlement, The direct payments extend the profit function, as follows:

$$Z_f = \mathbf{p_f}' \mathbf{x_f} + aa_f \ \mathbf{a_{fo}}' \mathbf{Subs_{fo}} \mathbf{D_f} \mathbf{x_{fo}} (\mathbf{a_{fo}}' \mathbf{x_{fo}})^{-1} + \mathbf{a_f}' \mathbf{Subs_{fo}} (\mathbf{I} - \mathbf{D_f}) \mathbf{x_f}$$

$$- \mathbf{x_f}' \mathbf{Q_f} \mathbf{x_f} /2 - \mathbf{d_f}' \mathbf{x_f} \qquad (47)$$

where:

$\mathbf{D_f}$ (N x N) diagonal matrix with the production decoupling ratio of activity i,

I (N x N) unit matrix.

3.5.2.2 Modulation of direct payments

Modulation reduces all direct, coupled and non-coupled, payments, beyond 5 000 euro per farm by a maximum of 5% in 2007. Modulation can, however, be avoided by transfers of direct payment entitlements. Farms with direct payments higher than the threshold of 5000 euro can transfer their direct payment entitlements to farms with direct payments lower than the threshold of 5 000 euro. To simulate these transfers that could be induced by modulation, the amount of reduced direct payments should be calculated during the optimisation process of the model to take modulation into account correctly. Therefore, the following constraint is introduced into the model:

$$md \geq \mathbf{a_{fo}}' \mathbf{Subs_{fo}} \mathbf{D_f} \mathbf{x_{fo}} (\mathbf{a_{fo}}' \mathbf{x_{fo}})^{-1} + \mathbf{a_f}' \mathbf{Subs_{fo}} (\mathbf{I} - \mathbf{D_f}) \mathbf{x_f} - mt \qquad (48)$$

where:

md the positive amount of direct payments subject to modulation,

mt the amount of direct payments free from modulation.

Modulation extends the profit function as follows:

$$Z_f = \mathbf{p_f}' \mathbf{x_f} + aa_f \ \mathbf{a_{fo}}' \mathbf{Subs_{fo}} \mathbf{D_f} \mathbf{x_{fo}} (\mathbf{a_{fo}}' \mathbf{x_{fo}})^{-1} + \mathbf{a_f}' \mathbf{Subs_{fo}} (\mathbf{I} - \mathbf{D_f}) \mathbf{x_f}$$

$$- \mathbf{x_f}' \mathbf{Q_f} \mathbf{x_f} /2 - \mathbf{d_f}' \mathbf{x_f} - md\ mp \qquad (49)$$

where:

mp the modulation percentage.

Although the MTR modulation imposes an increase in the modulation percentage in three steps from 3% in the first year, 4 % in the second year and 5% in the third, the following analysis is restricted to the simulation of the final modulation percentage.

3.5.2.3 Transfers of direct payment entitlements

Transfers of direct payments entitlements can occur both with and without transfer of land. A certain percentage of the entitlements that are transferred can, however, be withhold by the member state. For entitlement transfers with land, 10% of the entitlement can revert to the national reserve while, for sole transfers of direct payment entitlements, up to 30% of the entitlement can revert to national reserve. Seven additional constraints and seven additional variables are used to model the transfers of direct payment entitlements leaving open the possibility to realise these transfers with and without land transfers. Unobserved transaction costs can play a major role in the decision to transfer direct payment entitlements but are not modelled here.

First, a constraint determines per farm the amount of not activated direct payments entitlements, as follows:

$$na_f = \mathbf{a_{fo}}' \, \mathbf{x_{fo}} \, \mathbf{S_f} - aa_f \qquad (50)$$

where

na_f: not activated direct payment entitlements (in ha)

Then, following constraint calculates the average amount of direct payments per ha of not activated entitlements:

$$avs = \sum_f (na_f \;\; \mathbf{a_{fo}}' \, \mathbf{Subs_{fo}} \;\; \mathbf{x_{fo}} \, \mathbf{D_f} * (\mathbf{a_{fo}}' \, \mathbf{x_{fo}})^{-1}) / \sum_f na_f \qquad (51)$$

where

avs: the average amount of direct payments per ha of not activated entitlements

Farms with eligible land not yet used for activating decoupled direct payments will induce the direct payment entitlement transfers, because they are interested in buying entitlements. Following constraint calculates the free eligible land on each farm:

$$ef_f = \mathbf{a_f}' \, \mathbf{x_f} \, \mathbf{E_f} - aa_f \qquad (52)$$

ef_f : free eligible land

The farms with free eligible land can obtain additional entitlements both with as without land transfers. To distinguish between activated direct payments with land transfer and without land transfer, a constraint calculates the amount of land acquired by the farm, as following:

$$wl_f \leq \text{absolute value}(\mathbf{a_f}'\,\mathbf{x_f} - \mathbf{a_{fo}}'\,\mathbf{x_{fo}}) \qquad (53)$$

where

$wl_f \geq 0$

wl_f: land used for activating transferred direct payments with land transfer

In addition, a constraint limits the sum of activated direct payments of both with and without land transfer to be smaller than the free eligible land:

$$ef_f \geq wl_f + ol_f \qquad (54)$$

where

ol_f: land used for activating transferred direct payments without land transfer

The sum of not activated direct payment entitlements should always be larger than the sum of transferred direct payments, expressed by following constraint:

$$\sum_f na_f \geq \sum_f wl_f + ol_f \qquad (55)$$

The dual of equation (55) gives an indication of the price of the direct payment entitlements. A zero dual indicates that there is more supply than demand for the entitlements. The price will then be low. The higher the dual the more demand and the higher the price of the entitlements will be.

Due to the fact that the amount of direct payments per entitled ha is different across farms, it is possible that farms with a low amount of direct payments per ha increase the value of the entitlements by trading or vice versa. This is a way to avoid that direct payments are modulated[10]. We assume, however, that too many transactions costs are involved with at the same time buying and selling direct payments entitlements. Therefore, following complementary slackness constraint is added to the model:

$$ef_f * na_f = 0 \qquad (56)$$

Finally, the transferred direct payments extend the profit function, as following:

$$Z_n = \mathbf{p_f}' \ \mathbf{x_f} + wl_f \ avs\ rw + ol_f * avs\ ro - md * mp$$
$$+ aa_f * \mathbf{a_{fo}}' \ \mathbf{Subs_{fo}} \ \mathbf{x_{fo}} \ \mathbf{D_f} * (\mathbf{a_{fo}}' \ \mathbf{x_{fo}})^{-1} + \mathbf{a_f}' \ \mathbf{Subs_{fo}} \ (\mathbf{I} - \mathbf{D_f}) \ \mathbf{x_f}$$
$$- \tfrac{1}{2} \mathbf{x_f}' \ \mathbf{Q_f} \ \mathbf{x_f} - \mathbf{d_f}' \ \mathbf{x_f} \qquad (57)$$

where

rw: part of the transferred direct payments with land transfer not confiscated by the administration

ro: part of the transferred direct payments without land transfer not confiscated by the administration

3.5.2.4 Cross-compliance

Currently, the model assumes that every farm satisfies the conditions imposed by the member state. The model further assumes that these conditions do not generate additional costs. This is a reasonable assumption given that most of these conditions were already compulsory before the MTR.

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[10] E.g.: Farm A has 20 ha of direct payment entitlements of 300 euro/ha and farm B has 20 ha entitlements of 200 euro/ha. Farm A would receive the sum of the direct payments of 6000 euro and farm B 4000 euro. Therefore, 1000 euro of direct payments of farm A would be subject to modulation. To avoid modulation farm A and B can exchange 10 ha of direct payment entitlements resulting in a total of direct payments of 5000 euro for each farm. As a result of the exchange, the direct payments are not modulated anymore. (Note the model would simulate an exchange of 20 ha of direct payment entitlements with an average value of 250 euro per ha.)

3.5.3 Impact analysis

The model is calibrated and run for an FADN sub-sample of 159 arable and cattle farms for which data are available for the year 2002. Because of the non-representativeness of this sub-sample, one has to be careful to extrapolate the calibrated parameters and the simulation results to the whole sector. Being only indicative of the outcome of the MTR, the simulation results illustrate the various possibilities of the model to simulate differential effects of changes in the policy-controlled parameters.

The impact analysis focuses on the decoupling and modulation elements of the MTR. The following sub-sections show the effects of three policy-controlled parameters: the decoupling ratio, the modulation threshold and the modulation percentage on land allocation and gross margin according to farm size. Results are given in percentage changes with respect to the baseline.

3.5.3.1 Impact analysis of the decoupling ratio

Figure 15 shows the effects of increasing the decoupling ratio from 0 to 100% on land allocation among different types of crops with a modulation threshold set at 5000 euro and percentage set at 5%. As the decoupling ratio increases to 100%, farms substitute crops that were not subsidized before the MTR for crops that were subsidized before the MTR. This substitution effect is larger for previously subsidized crops such as wheat and barley than for previously subsidized fodder crops such as fodder maize. For the former, the decline reaches 6% while, for the latter, the decline reaches 4% for the full decoupling scenario compared to the baseline of 2002. Substitution among fodder crops is tighter as a result of the feeding constraints and few alternative fodder crops. Effects of the MTR on allocation of non eligible crops are minor because the simulation limits the activation of decoupled direct payments to the maximum amount granted during the baseline.

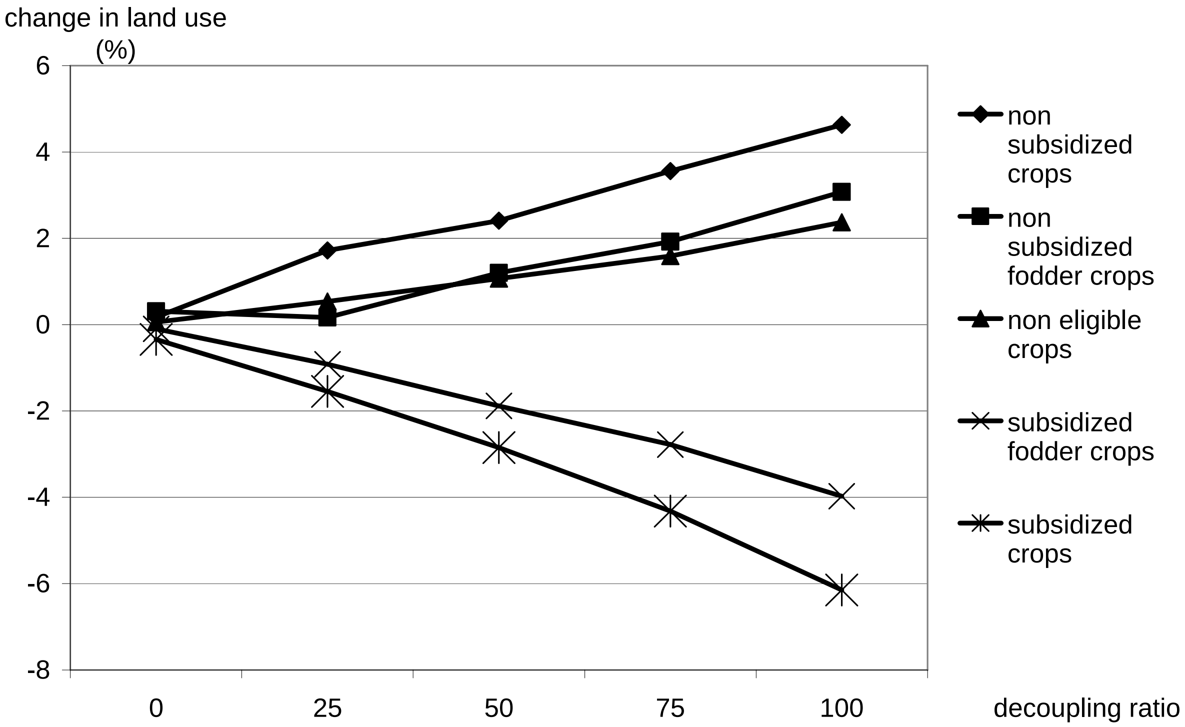

Figure 15. Changes in land allocation among crop categories with respect to the decoupling ration

Figure 16 shows the effects of increasing the decoupling ratio from 0 to 100% on farm gross margins across farm sizes with a modulation threshold set at 5000 euro and percentage set at 5%. Effects of the MTR on farm gross margins are relative smaller than effects on land allocation. As expected, a complete decoupling of the direct payments generates a positive effect on farm gross margins across all farm sizes. The larger positive effect in gross margin for farms of smaller size is due to the 5% modulation of direct payments above the threshold of 5000 euro.

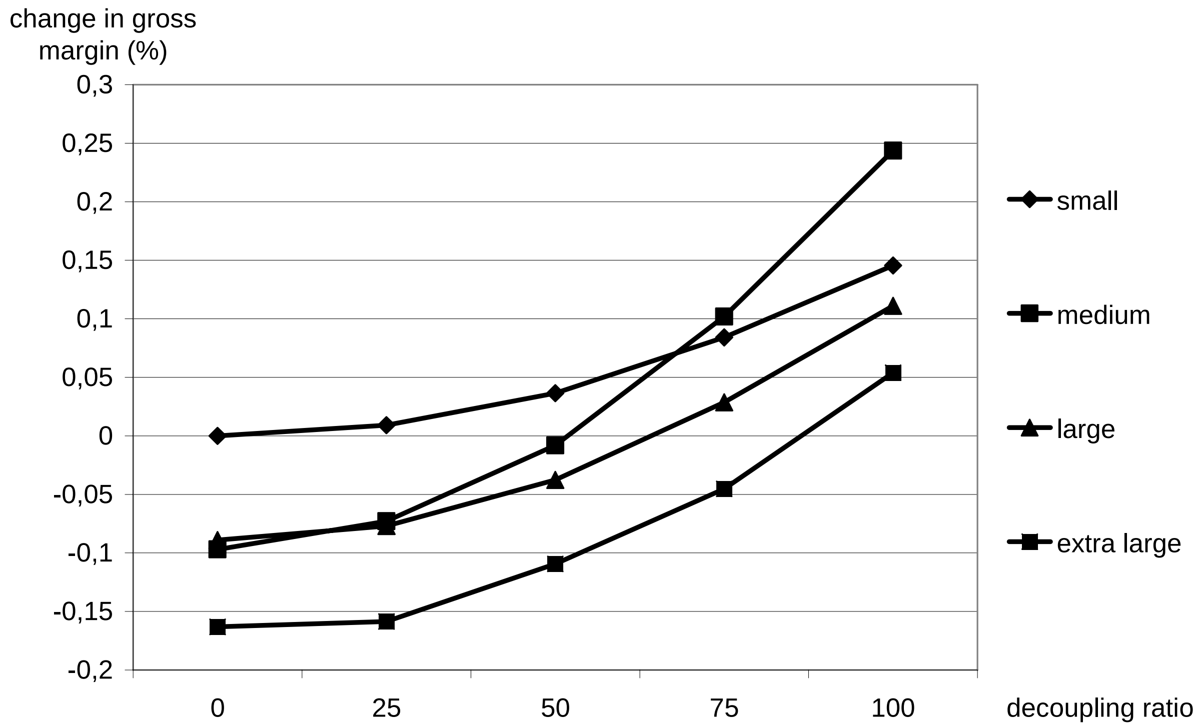

Figure 16. Changes in farm gross margin with respect to the decoupling ratio across farm sizes

3.5.3.2 Impact analysis of the modulation

Figure 17 shows the effects of increasing the modulation percentage from 10 to 30% on farm gross margins across farm sizes with a modulation threshold set at 5000 euro and full decoupling. As expected, the effects of an increasing modulation percentage on farm gross margins are higher on farms of larger size. Since small farms with a farm gross margin lower than 9600 euro do not receive an amount of direct payments exceeding the threshold of 5000 euro, these farms are not affected by this simulation. The extra large farms with a farm gross margin higher than 48000 euro have the highest share of direct payments above the 5000 euro threshold and, therefore, see their farm gross margin reduced by almost 0,8% with a 30% modulation. The medium and large farms with a farm gross margin lower than 19200 and 48000 euro respectively see their farm gross margin reduced by about 0,3% with a 30% modulation.

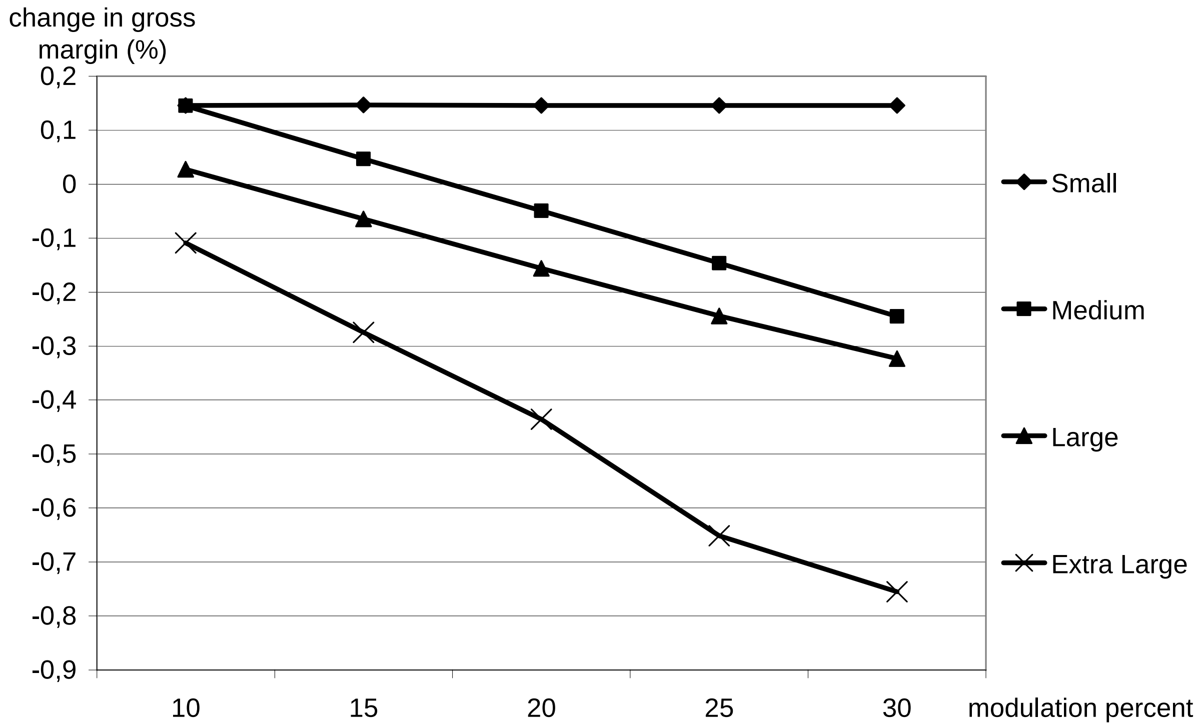

Figure 17. Changes in farm gross margin with respect to the modulation percentage across farm sizes

Figure 18 shows the effects of decreasing the modulation threshold from 5 000 to 2 000 euro on farm gross margins across farm sizes with a modulation percentage set at 5% and full decoupling. As expected, a lower modulation threshold leads to a decline in farm gross margin across all farm sizes. This decline is larger for farms of smaller size. A reduction of the modulation threshold combined with an increase in the modulation percentage results in even larger decline in farm gross margins.

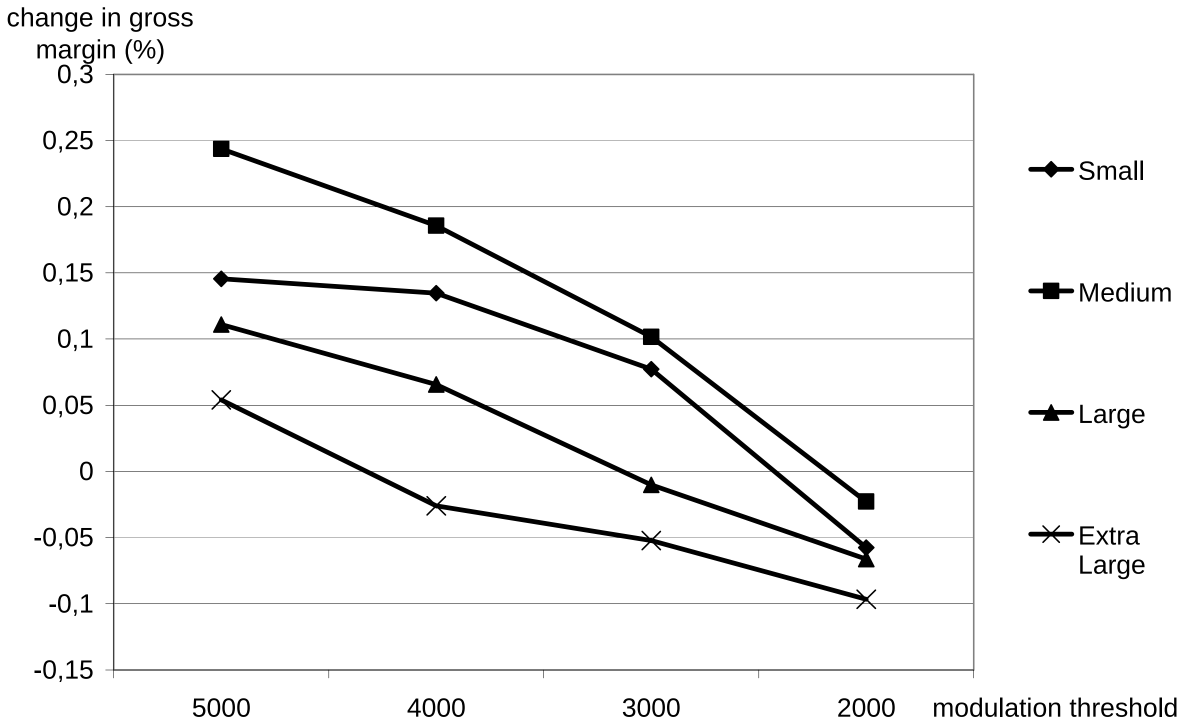

Figure 18. Impact of changes in the modulation threshold according to farm size

3.6 Conclusions

3.6.1 Conclusions with respect to the applications

The simulation results point out that the decoupling of direct payments decrease farmland allocated to crops that were subsidized in the baseline and increase farmland allocated to crops that were not subsidized in the baseline. In contrast, farmland allocated to crops that are not eligible to direct payments does not vary, a consequence of maximising the activation of the single payment entitlements on available farmland. In addition, the simulation results confirm the positive but still minor impact of decoupling direct payments on the farm gross margin. They also show the negative but still minor impact of modulating direct payments on the gross margin of the farms with the largest size. Although these illustrative simulation results show the capacity of a farm-based PMP model to differentiate the results according to farm size, they can be also easily be differentiated according to other parameters available in the data base such as farm localisation and type.

3.6.2 Modelling lessons

The experience from the SEPALE exercise with respect to future modelling challenges is discussed in the three next subsections. First, the advantages of PMP in SEPALE are listed. Next, the limitation of the functional form, which is inherent to the application of PMP in SEPALE, is discussed. The chapter finishes with some specific encountered problems in this application.

3.6.2.1 PMP advantages

PMP has renewed the interest in mathematical modelling for agricultural and environmental policies for several reasons. The main advantages of the PMP approach are the simplicity of the modelling of bio-economic constraints or policy instruments and the possibility to make use of very few data to model agricultural policies, while being able to generate plausible results. The plausibility of the results is obtained from the possibility of the introduction or real-world constraints and of the calibration step. The calibration avoids the critique of one of the reviewers on Chapter 2: "the model's inability to simulate baseline conditions, resulting form optimum conditions that do not prevail on farms."

The SEPALE application also illustrates how PMP can be used with large farm-level samples. This not only makes it possible to account for the individual farm structure, but also for the direct payment entitlement trade mechanisms. The results prove the relevance of the model for simulating possible alternatives to the implementation of the CAP Mid Term Review, but this example is certainly not limitative. The possibility of distinguishing the effects according to farm size or other criteria such as region or farm type is one of the main advantages of the individual farm-base modelling. It also opens avenues to model structural changes of the sector.

3.6.2.2 PMP limitations

The plausible results generated by a PMP model do, however, not guarantee that the response is correct. At this stage, some words of caution need to be addressed on the model specification, which determines the model response, and should be reminded for the interpretation of the simulation results.

First, the simplicity of the quadratic cost function for parameter calibration is obtained by suppressing all input prices and off-diagonal elements from the cost function. This simplicity implies that we can not simulate explicitly changes in yields as consequence of changed input use such as fertilizer, seed or pesticides at the farm level. It is, however, possible to see changes in input use due to the changed output mix and shifts of the land use between farms. The quadratic form of the cost function also imposes marginal cost functions that are linear and increasing with production quantities.

Second, while avoiding aggregation errors, the definition of a cost function at the farm level is prone to a self-selection problem due to the missing representation of the farm behaviour with respect to activities not observed during the baseline.

Third, constraining farmland over the F farms in the sample, which allows for competition and transaction of farmland among farms gives to the model a source of jointness at the aggregate level. This source of jointness among activities at the aggregate level as well as the linearity of the increasing cost function provide a long-term perspective to the rate of farm adjustment to changing economic conditions that is, however, mitigated by the fixed input proportionality and activity selection assumptions. For example, in simulation runs, farms can trade land to each other in the sample and re-allocate it among their baseline activities but cannot substitute one input for another and initiate new activities.

The shortcomings raised from the use of a simplified quadratic cost function point out the use of a flexible multi-input multi-output cost function and panel data to estimate its numerous parameters. The shortcoming from the self-selection problem is difficult to overcome without *ad hoc* modelling decisions.

The problems of assessing correctly the response behaviour are illustrated by the few ex post simulation exercises that have been done.

Heckelei and Britz (2000) compare the percentage national deviation of simulated production activity levels from the observed activity levels in 1994 for three approaches. The original PMP approach (Howitt, 1995a), an intelligent no-change scenario and their approach that combines PMP with Maximum Entropy (ME) are put side by side. The original PMP approach shows rather high deviations for some major crops, while the intelligent no-change forecast is comparatively close to observed production activity levels. The 1992 CAP-reform had, apparently, in France a relatively small impact on the aggregate crop rotation apart from the set-aside. The fit of the ME-PMP approach based on the cross sectional sample is rather promising, because it provides in most cases better simulated values than the no-change results.

Gocht (2005) compares the simulation behaviour of different PMP approaches and concludes that all approaches which uses the first step of the Howitt (1995a) approach show large percentage absolute deviations. The use of ME or exogenous supply elasticities has barely improved the results.

Arriaza and Gomez-Limon (2003) perform a comparative study that besides PMP also includes NMP models. This paper indicates that two modelling approaches that include expected total gross margin and a qualitative total risk index outperforms other modelling alternatives. These approaches yield the best results in terms of predictive capacity to the 1992 EU agricultural policy reform. Although the PMP approach performs well, it has the limitation of excluding crops that are not present in the base year. However, if the excluded crops are not regarded as a real alternative for the farmer, this approach yields satisfactory predictions. Arriaza and Gomez-Limon (2003), however, indicate that all the conclusions obtained are completely dependent of the context situation and, therefore, of the particular case study. This remark is of course valid for the other validation exercises too.

3.6.2.3 Numerical solution problems

Another important but often not in detail described problem of operational modeling is optimizing the developed simulation model. Currently, GAMS with the CONOPT3 solver optimizes the proposed model. Three problems arise during optimization, the use of the absolute value function (ABS), the discontinuities in the model and the complementary slackness constraints. Due to the size of the model, i.e. the large number of variables and constraints, solving the optimization problems remains the most difficult task in current analysis.

The ABS function

The use of the ABS function in GAMS requires that the model runs as a dynamic non linear programming (DNLP) model instead of a non linear programming (NLP) model. The NLP solvers used by GAMS can also be applied to DNLP models. However, it is important to know that the NLP solvers attempt to solve the DNLP model as if it was an NLP model (Drud, 2004).

Therefore, Drud (2004) suggest two approaches to rewrite the ABS function in a NLP model. In the first approach, the term z = ABS(f(x)) is replaced by z = fplus + fminus, fplus and fminus are declared as positive variables and they are defined with the identity: f(x) =E= fplus - fminus. The discontinuous derivative from the ABS function has disappeared and the part of the model shown here is smooth. The discontinuity has been converted into lower bounds on the new variables, but bounds are handled routinely by any NLP solver. The feasible space is larger than before (Drud, 2004).

The second approach relies on a smooth approximation. A smooth GAMS approximation for ABS(f(x)) is SQRT(SQR(f(x)) + SQR(delta)) where delta is a small scalar. The value of delta can be used to control the accuracy of the approximation and the curvature around f(x) = 0.

The approximation shown above has its largest error when f(x) = 0 and smaller errors when f(x) is far from zero. If it is important to get accurate values of ABS exactly when f(x) = 0, then Drud (2004) suggest following smooth approximation:

SQRT(SQR(f(x)) + SQR(delta)) - delta

The presented model has employed both the smooth as the non-smooth reformulation of the DNLP to the NLP model. In contrast to what Drud (2004) suggest, the value of the objective function shows that in current model the DNLP formulation is in all simulations better than the reformulations to NLP.

Complementary slackness constraints

A complementary slackness constraint prevents farms to buy and to sell direct payments entitlements at the same time.

$ef_f * na_f = 0$

However, the use of so-called complementary slackness constraints is a problem in any NLP model (Drud, 2004). The feasible space consists of the two half lines: ($ef_f = 0$ and $na_f \geq 0$) and ($ef_f \geq 0$ and $na_f = 0$). Unfortunately, the marginal change methods used by most NLP solvers cannot move from one half line to the other, and the solution is stuck at the half line it happens to reach first (Drud, 2004). One way to solve the complementary slackness constraint problem in current models is the use of different starting points. The objective value of the different simulations should then determine the final retained solution. The problem here is that a good starting point for one farm can be a bad starting point for another.

Discontinuities in the model

The solver stops each simulation run with following message.

```
** Feasible solution. The tolerances are minimal and
   there is no change in objective although the reduced
   gradient is greater than the tolerance.
```

The message indicates that there is no progress at all in the solution process. However, the optimality criteria have not been satisfied. This problem with the presented model is caused by discontinuities. A complex nonlinear model may — and frequently will — have multiple locally optimal solutions. In most realistic cases, the number of such local solutions is unknown, and the quality of local and global solutions may differ substantially. Therefore multi-extremal decision models can be very difficult, and — as a rule — standard optimization strategies are not directly applicable to solve them (Pinter, 2001). Here too, global optimization could be a solution to the problem. We have tried Global Optimization (GO) solvers, but unfortunately, they did not succeed to solve the problem. One of the GO doesn't even accept problems with the size of our model.

3.6.2.4 Chosen solution

At this moment, no satisfying solution has been found. The main path for improvement can be expected from the translation from the model to an MPEC (Mathematical Programming with Equilibrium Constraints) model and the use of the MPEC solver in GAMS. This solver is, however, only in beta status and gives also no guarantee for success.

Due to the problems of the simulation of the transactions of direct payment entitlements, following applications only include the equations to calculate the decoupled payment and modulation without the possibility of transfers.

This simplification implies that during simulation no transfers of direct payment entitlements occur. A farm that does not activate the entitlements, therefore, does not receive the direct payments and other farms can not buy and, thus, not benefit from the free direct payment entitlements. As a result, farms in the following simulations try to activate as much as possible the entitlements. This reflects a situation with very high transaction costs for the transactions.

Chapter 4 PMP extension of SEPALE: modelling the impact of policy reforms on Belgian sugar beet suppliers

Chapter 4 extends the basic farm model SEPALE, described in previous section, with a module to deal with quota, an instrument that is often applied in European agricultural policies.

Quotas enable policy makers to internalise national resource constraints at farm level. Quota or production permits exist in both agricultural policies, such as the CAP (Common Agricultural Policy), as in environmental policies. Examples of production quota in agricultural policies are the quota for milk, suckler cows, sheep and sugar beet. Supply within quota limits ensures suppliers a high guaranteed price for milk and sugar or subsidies for sheep and suckler cows. These quotas allow for better control of the total budget for price or subsidy support, which is here the national resource constraint. Manure quota in Flanders is an example of quotas in environmental policies.

Quota in MP models can be represented by simple constraints and are, as such, easy to deal with. However, certain specificities of quota put, in farm-level calibrated programming models, three major challenges to modellers.

One of the problems of quota representation is that the marginal cost - price equilibrium is often not satisfied anymore. The first challenge is therefore to estimate the correct marginal costs or the rent of quota, which is the difference between the price and the marginal cost.

The second challenge is to incorporate the possibility of oversupply, i.e. supply higher than the quota limit, or undersupply, i.e. supply lower than the quota limit. If there is a large penalty for oversupply (e.g. for environmental production permits) the producers tend to supply less. If there is a penalty for undersupply, farms oversupply (e.g. for sugar beet). Over- or undersupply depend on the level of the penalty, the variability of production, the possibilities to adapt supply and the profitability of supply both within as outside quota.

The third challenge is to model the transfer of quota among farms. In case of a market for quota, observations of the price and the transfers exist in most cases, as for example for dairy quota in the Netherlands. This is, however, often not the case. For sugar beet in the EU, Bureau *et al.* (1997) mention strong rigidities and transfer costs in the quota market.

Chapter 4 describes an approach to cope with the three major challenges of quota modelling in the case of sugar beet. To illustrate the approach, the model is applied to analyse the sugar CMO reform proposals. The approach, currently applied to sugar beet supply, could be useful for different types of quota.

The chapter starts with an overview of the EU sugar CMO and the proposed reforms, followed by a discussion of the three major issues: C sugar beet supply representation, quota rent estimation and across farms quota transfer. The chapter also includes an application and discussion of the presented approach.

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4.1 Introduction

4.1.1 The EU sugar CMO

Under the sugar CMO, the EU enforces a quota system for sugar beet deliveries to factories and, consequently, sugar supplies to the EU market. The quota system distinguishes an "A" quota sold at full price support through the minimum sugar beet price which is, however, discounted by a 2% producer levy, and a "B" quota receiving substantially lower price support due to a maximum of 39.5% producer levy being charged on the minimum sugar beet price. Any sugar beet and sugar quantities sold beyond the combined A and B quotas and called "C" sugar have to be exported at world prices without refund. Chicory for inuline syrup production is also managed by the sugar CMO, under which Belgium detains two thirds of the EU inuline quota that are, however, not always filled (Commission of the European Communities, 2004b). Sugar used for alcohol and bio-ethanol, the so-called industrial sugar, is excluded from the production quota arrangement and is traded at world prices (see details in Commission of the European Communities, 2004b).[11]

Instead of applying the A and B discriminatory quota system, sugar factories in Belgium offer a pooled A and B price for all quota beets to sugar beet farms. Since the different proposals of the European Commission to reform the sugar CMO also simplify the quota arrangements by merging A and B quotas into one single quota (Commission of the European Communities, 2004a), we subsequently use index A to refer to sugar beet quantity and price equal to this pooled quota and price respectively and index C to refer to all sugar beet quantity and price outside the production quota arrangements, including for industrial use.

[11] Note that the June 2005 sugar reform proposal extends the exclusion from the quota arrangement to sugar that is destined for chemical and pharmaceutical use with a high utilisation of sugar (Commission of the European Communities, 2005). Thanks to this extension, the European Commission expects to satisfy the request made by the 2005 World Trade Organisation (WTO) panel on sugar to comply with its export subsidy commitments as agreed upon at the conclusion of the Uruguay round.

4.1.2 EU sugar CMO reform

Since the agreement of the June 2003 Common Agricultural Policy (CAP) reform which left the European sugar Common Market Organisation (CMO) unaffected, the European Commission has proposed various options to reform the sugar CMO (Commission of the European Communities, 2003a, 2003b and 2004a). These options included reductions in quota or price, or both, and alternative compensation levels and mechanisms, whether or not decoupled. The July 2004 reform proposal that would cut the minimum sugar beet price by 37% and the sugar quota by 16% and add a decoupled subsidy of 60% of the price cut has been rejected. In June 2005, the European Commission has then launched a new proposal for cutting the minimum sugar beet price by 42,6% over two years from the 2006/07 campaign, but leaving the white sugar production quota at its current level of 17,44 million tonnes with the possibility to raise it by one million tonnes (Commission of the European Communities, 2005). Under this proposal, to offset the fall in the minimum beet price, the sugar beet farms would receive 60% compensation aid that would be incorporated into the new single farm payment. In November 2005, the European Council has, finally, decided to cut the minimum sugar beet price with 39,5% with a compensation of 64,2% of the price reduction.

This reform brings therefore the sugar CMO, of which the current system expires in July 2006, into line with the rest of the decoupled CAP. Confronted with a potential surge in imports, estimated at 2,2 million tonnes of sugar as a result of the full implementation of the Everything But Arms (EBA) agreement in 2009, the European Commission further expects that a proposed quota buy-up scheme could withdraw 4,6 million tonnes of sugar quota during the first two years and, hence, substantially reduce subsidised exports, which may facilitate the current World Trade Organisation negotiations.[12]

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[12] Funded by a levy of 126,4 euro/tonne in 2006/07 falling to 64,5 euro/tonne of sugar quota in 2008/09, the voluntary quota buy-up scheme would pay out 730 euro in 2006/07 falling to 420 euro in 2009/10 for every tonne of sugar quota renounced.

4.1.3 Other EU sugar CMO reform analysises

There are a number of recent studies that analyse the impact of possible reforms of the sugar CMO. One of these studies is the assessment conducted by EuroCARE, at the request of the European Commission (http://www.eurocare-bonn.de/profrec/sugar/sugar_e.htm), relying on complementary iterative economic models to analyse six reform options for the sugar CMO. At the international level, the recursive-dynamic, spatial world trade WATSIM model simulates the international trade impacts of reform options on third countries and international prices. At the EU member state level, the calibrated, comparative static, partial equilibrium CAPSIM model represents agricultural markets. At the NUTS 2 regional level, the regional non-linear programming models of the activity-based supply module of the CAPRI model estimate land use and crop mix, with specific attention to the peculiarities of the out-of-quota sugar beet production. At the individual farm level, simple farm management models predict the supply responses of individual sugar beet farms, which can be aggregated to regional and national supply response.

Another recent study, by Frandsen *et al.* (2003), estimates and calibrates supply responses and quota rents at the level of each member state. They incorporate these member state supply responses and quota rents into a global computable general equilibrium model, an adapted version of the GTAP model, to compare the effects of price and quota reductions on EU production and trade.

Because individual member states include sugar beet farms or regions that produce at various levels of marginal cost, aggregation errors can lead to an under- or overestimation of the impact of a fall in the minimum sugar beet price or quota. This applies in particular for large changes in price and quota that are currently proposed. Moreover, the simplified representation of supply responses at the member state level can hardly account for domestic tradable quota from high to low cost farms. It may well be assumed that because of these quota transfers, the member states' response for producing at lower prices will fall less dramatically.

This study offers an alternative approach to model supply responses taking into account the heterogeneity of farm responses, precautionary C sugar beet supply behaviour and the transfer of delivery rights within any given EU region or member state. This choice is driven by the fact that consistent econometric estimates of sugar supply functions in the EU have proved difficult to obtain as a result of the specific features of the sugar regime (Bureau *et al.*, 1997) but also the other complex CAP instruments. We rely on mathematical programming to explicitly optimise supply responses at the farm level.

While Fraser *et al.* (1997) also adopt a disaggregated approach to model individual farm responses using the calibration Positive Mathematical Programming (PMP) method to analyse the impact of alternative mechanisms for reallocating sugar beet production contracts on farm production and income, our approach differs on three important elements. First, in contrast to Fraser *et al.* (1997), our model explicitly simulates changes in C sugar beet supply. Second, we do not impose a perfect market for sugar beet quota and, third, our model relies on a different calibration approach (see Chapter 3).

This model is used to analyse the economic effects of various combinations of sugar beet price and quota reductions, including the June 2005 European Commission's proposal on a sample of Belgian sugar beet farms. Unlike the Frandsen *et al.* (2003) general equilibrium model and the EuroCARE's iterative modelling, the current stage of development of this farm model does not endogenize market prices. This may overestimate the predicted farm responses. The model also does not account for trade and economy-wide effects in the EU or worldwide. As such, it remains however possible to put this farm model into interaction with larger economic models functioning at the EU or world level to incorporate price endogeneity.

To model sugar beet supply at farm level, we need to tackle three major issues: C sugar beet supply representation, quota rent estimation and across farms quota transfer.

4.2 C sugar beet supply

The main challenge of modelling sugar beet supply consists in the representation of C sugar beet supply. Every sugar beet farm of the Belgian FADN sample supplies some amount of C sugar beet beyond the quota limit. For example, in 2002, the supply of C sugar beet accounts for about 13% and 18% of total sugar beet supply in the sample and the country respectively. Expert opinions tend, however, to agree that supplying sugar beet at prices close to the world market price is not sustainable in Belgium. The observed supply of C sugar beet has several, but difficult to model, motivations.

C sugar beet supply can, just like any crop, be influenced by the marginal revenue, the C sugar beet price and the marginal costs. This element of C sugar beet supply can, as for all other crops, be represented in the profit function of sugar beet.

Gohin and Bureau (2006) distinguish three other driving factors for C sugar beet supply in the EU. First, the high in-quota price can cover the fixed cost allowing the production of C sugar beet at low prices. This can certainly be an explanation in the short run but more difficult to defend in the long run. Therefore, we don’t hold back this element as an explaining factor for C sugar beet supply. C sugar beet supply in Belgium is mainly induced by the two other driving factors indentified by Gohin and Bureau (2006): i) C sugar beet supply as insurance to prevent losses of profit from quota under filling and ii) the expectations that future delivery rights are based on past output levels. This last element is certainly important in Belgium because sugar factories can withdraw delivery rights not filled in consecutive years.

Figure 19 presents these two driving factor and their relation with influencing parameters.

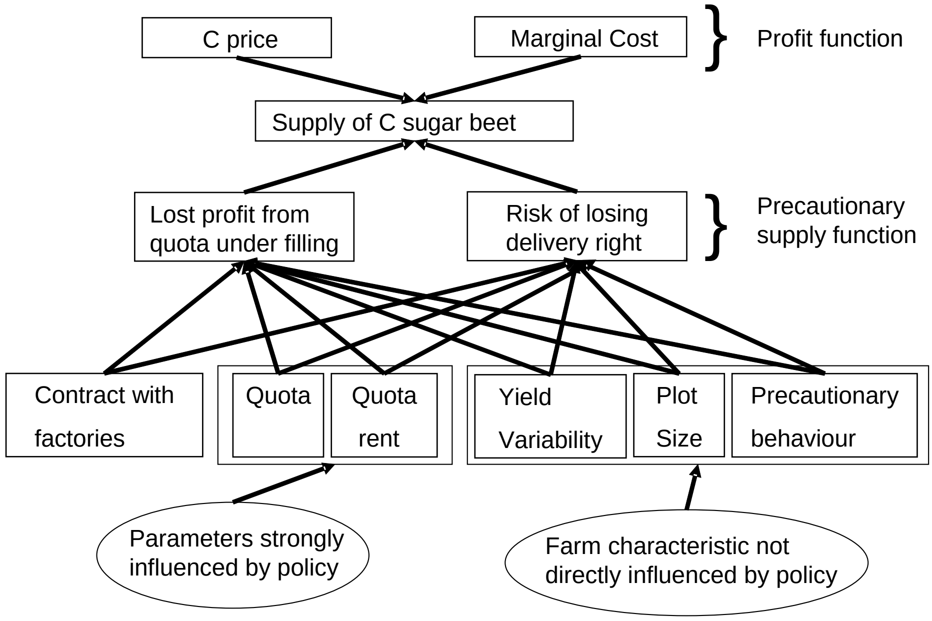

Figure 19. Determining factors of the C sugar beet supply

The two following subsections each describe a method that can simulate changes in the precautionary behaviour as a function of external changes. First, an approach similar to Adenauer *et al.* (2004) that explicitly considers yield uncertainty to model C sugar beet supply is presented. The approach illustrates the logic and profitability of C sugar beet supply even if the marginal costs are higher than the C sugar beet price. It shows the economic mechanism behind the first element of the precautionary behaviour and indicates the driving factors of it.

The approach is, however, only introduced and not applied here because it deals with only the first of the two elements of precautionary supply and because also Adenauer and Heckelei (2005) have shown that it can not fully justify the observed C sugar beet supply.

The second approach is based on a precautionary supply function that simulates the influence of relevant policy elements on the precautionary behaviour. The precautionary supply function extends the basic SEPALE model, described in Chapter 3, and is applied to a sample of Belgian sugar beet farms.

4.2.1 Yield variation function

Adenauer *et al.* (2004) have introduced an expected value approach to describe the sugar supply behaviour. The basic idea is that sugar beet supply is a stochastic variable. The sugar beet grower bases his land allocation choice on the expected supply x. Because of weather conditions and other external factors certain years his actual production x_s may be higher than the expected supply x while in other years it is lower. In the model, the production x_s is assumed to be symmetrically distributed around the expected supply x following a logistic distribution[13] with variance $\pi^2 v^2/3$.

$$P(x_s) = e^{-(x_s-x)/v} / (v\,(1 + e^{-(x_s-x)/v})^2) \qquad (58)$$

$$D(x_s) = (1 + e^{-(x_s-x)/v})^{-1} \qquad (59)$$

where:

x is the expected supply of sugar beets,

x_s is the stochastic production of sugar beets,

m is the sugar beet quota,

v is a parameter that determines the yield variability

Both the probability and the distribution function of the logistic are illustrated in Figure 20.

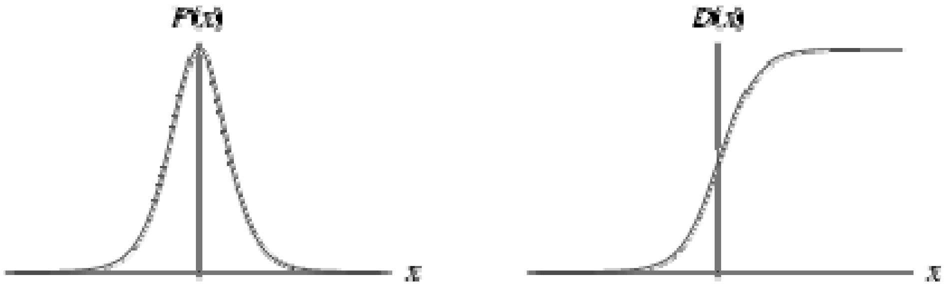

Figure 20. Probability and distribution function of the logistic distribution

[13] We prefer the logistic distribution to the normal distribution (as has been used by Adenauer *et al.*, 2004) because in contrast to the normal distribution the logistic distribution can be analytically integrated.

The logistic distribution function with as mean the available quota expresses the cumulative probability of producing C sugar beet with an expected supply of x. This means that if a sugar beet grower has quota m and decides to supply x, his probability that the last produced unit is C sugar beet is expressed by:

$$(1 + e^{-(x-m)/v})^{-1} \quad (60)$$

A sugar beet grower deciding to supply an amount m will have in 50% of the years a production above the quota m and in the other years a production below the quota m.

Because the distribution function expresses the probability of producing C sugar beet, it allows to describe the marginal revenue function for each farm with quota m and the variance on the expected supply $\pi^2 v^2/3$ in function of the expected supply x as follows:

$$MR = p_a - (p_a - p_c) * (1 + e^{-(x-m)/v})^{-1} \quad (61)$$

where:

MR is the marginal revenue of sugar beet,

p_a is the A sugar beet price,

p_c is the C sugar beet price

Figure 21 illustrates the resulting marginal revenue function and shows that the marginal revenue of a sugar beet farmer deciding to grow sugar beets to fill exactly his quota is ($p_a + p_c$ / 2). In 50% of the years the sugar beet farmer receives for his last supplied unit Pa and in the other years Pc.

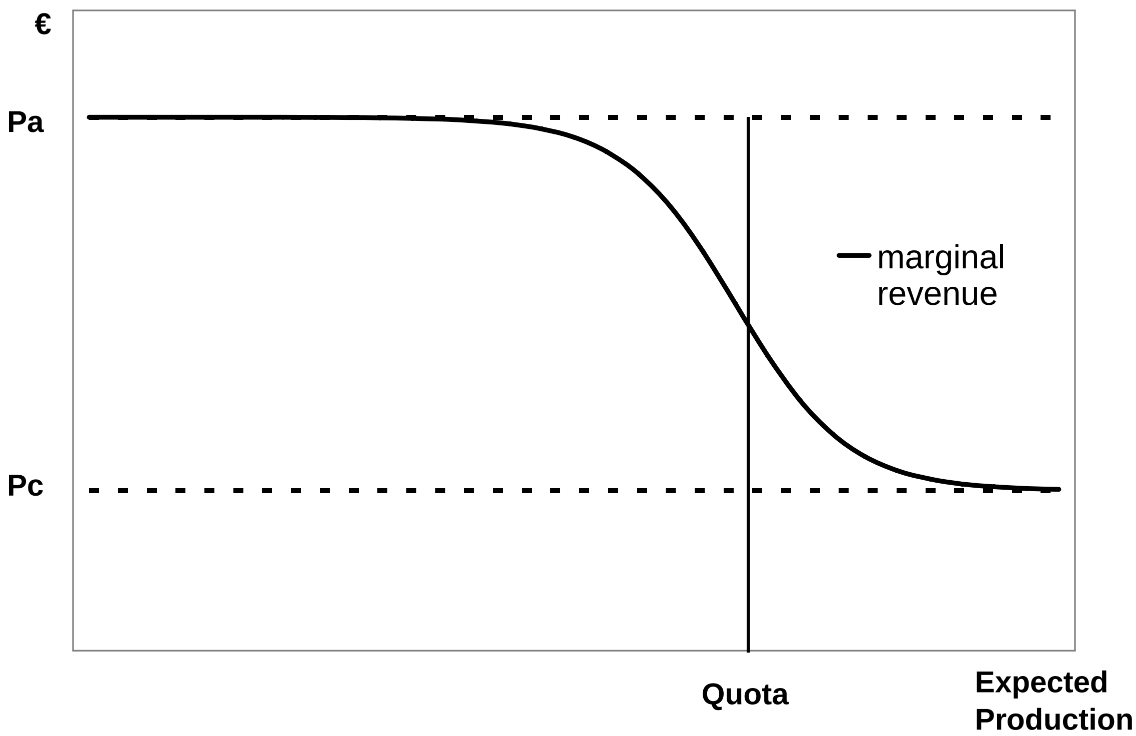

Figure 21. Continuous marginal revenue function based on a stochastic logistic distribution of supply

Integrating this marginal revenue function to x allows describing the total revenue in function of the sugar beet prices, the expected supply x, the variance of the expected supply $\pi^2 v^2/3$ and the quota m.

$$TR = \int_0^x MR\, dx = p_a x - (p_a - p_c) * (v \ln(e^{(m/v)} + e^{(x/v)}) - m) \qquad (62)$$

where:

TR is the total revenue of sugar beet,

p_a is the A sugar beet price,

p_c is the C sugar beet price

Figure 22 illustrates the resulting total revenue function and shows that stochastic supply lowers the total revenue of most sugar beet growers, because the price received for over-supply (p_c) does not compensate the price that is not received during years of under-supply (p_a). If the sugar beet farmer produces much more or much less than his quota, the difference between stochastic and deterministic supply disappears. In that case, there is no difference in marginal revenue for good and bad years. The marginal revenue is then either Pa or Pc. The high revenue from a good year will perfectly compensate the low revenue from a bad year. Sugar beet could then be simulated similar to other crops, no precautionary supply function is necessary.

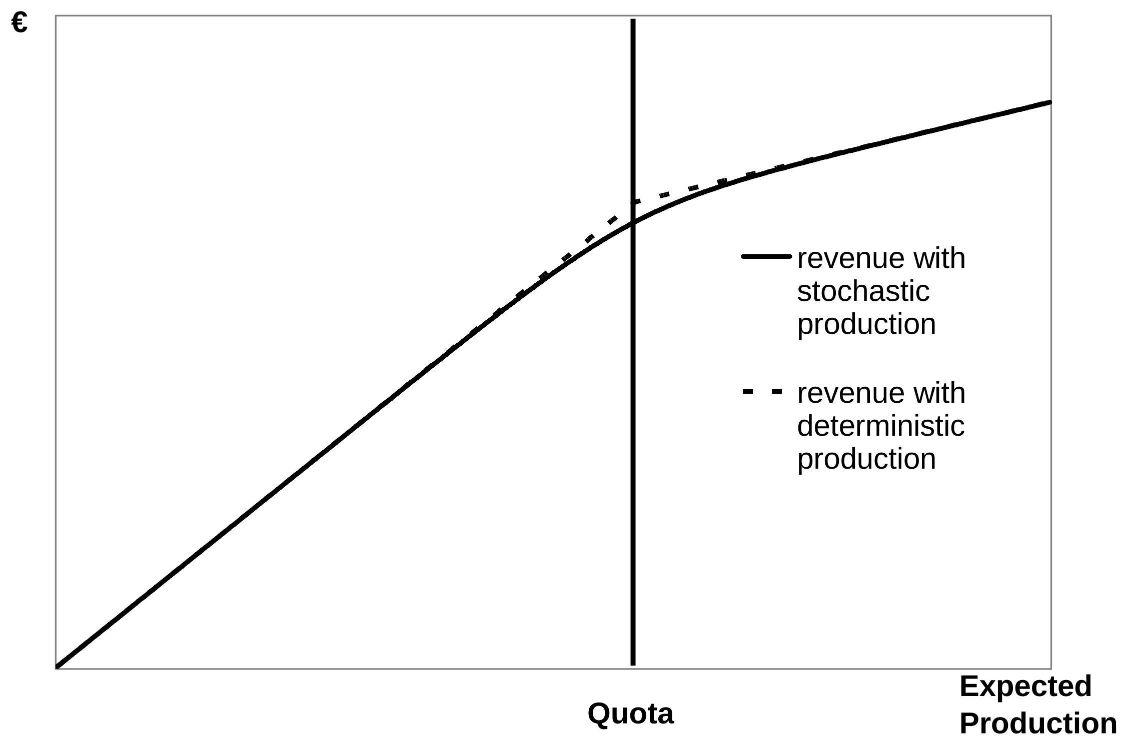

Figure 22. Total revenue function based on a stochastic production versus deterministic production

Until now, we have assumed a variance independent of total supply. In reality, however, the variance will depend on the expected supply. In the extreme case, if the sugar beet grower decides to produce no sugar beets, the variance will be zero. The variance will increase with increasing average supply x.

Therefore, the parameter that captures the variance v is replaced by v’x in the total revenue function with v’ = v/x and a new total revenue function is obtained as follows:

$$TR = p_a x - (p_a - p_c) * (v'x \ln(e^{(m/v'x)} + e^{(x/v'x)}) - m) \quad (63)$$

Figure 23 illustrates the resulting total revenue function. It shows that because of the increasing variance in terms of supply, the revenue stays longer below the deterministic level in case of a supply above the quota.

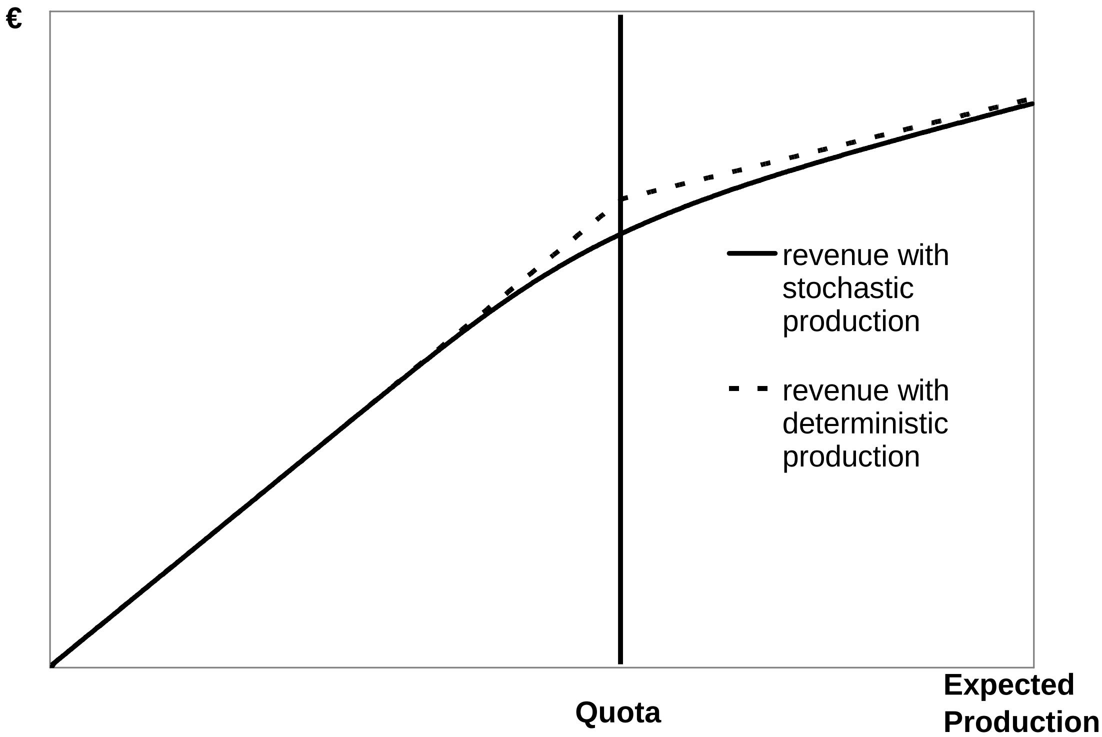

Figure 23. Total revenue function based on a stochastic production with a variance depending on supply versus deterministic production

From this adjusted total revenue function a new marginal revenue function can be derived.

$$MR = \partial TR / \partial x = p_a - (p_a - p_c) * (-e^{(m/v'x)} m / ((e^{(1/v')} + e^{(m/v'x)}) x) + v'\ln(e^{(1/v')} + e^{(m/v'x)})) \quad (64)$$

Figure 24 illustrates this function, which is in contrast to Figure 21 not symmetric around the quota.

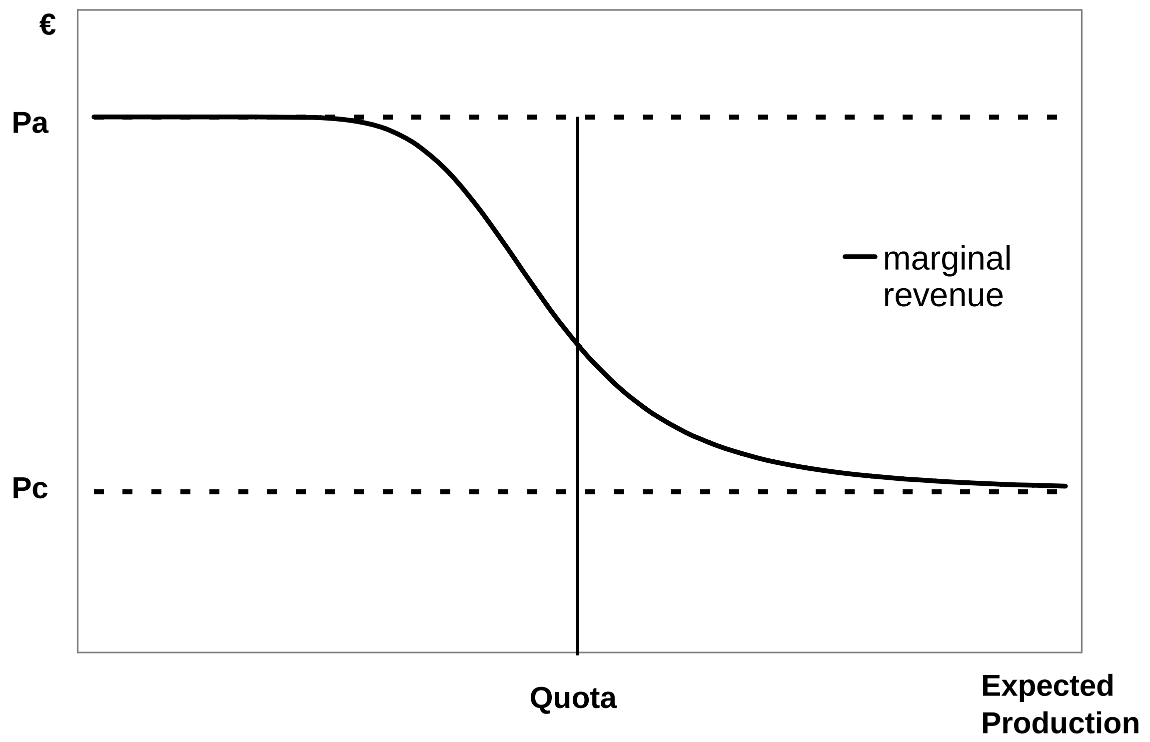

Figure 24. Continuous marginal revenue function based on a stochastic distribution of production with variable variance

Once the revenue functions are constructed, sugar beet can be modelled similar to other crops. The revenue function is combined with a cost function in following farm level profit function for sugar beet in algebraic notation:

$$\text{Profit sugar beet} = p_a\, x - (p_a - p_c) * (v'x \ln(e^{(m/v'x)} + e^{(x/v'x)}) - m) - q/2\, x^2 - d\, x \quad (65)$$

where:

q is a quadratic cost function parameter,

d is a linear cost function parameter

m and v' are farm specific constants that can be calculated from the observations in the FADN data. The expected supply x is the decision variable and q and d are the cost function parameters that can be calibrated similar to other crops.

The interesting aspect of the approach based on yield variability is that it shows that with a marginal cost higher than the C sugar beet price, it is economically reasonable to supply on average a certain percentage of C sugar beet. Figure 24 also illustrates that the percentage of C sugar beet that should be supplied, increases with increasing sugar beet prices (both A and C). Decreasing marginal costs also lead to an increase of the C sugar beet supply.

Adenauer and Heckelei (2005), however, indicate that optimising an expected utility based on yield variability cannot fully justify the observed C sugar beet supply. The observed C sugar beet supply would imply that the marginal costs are much lower compared to estimates from the marginal costs. To overcome this problem, Adenauer *et al.* (2004) add a virtual quota to the observed quota.

As pointed out before, one of the reasons for the incomplete reflection of C sugar beet supply is that the approach deals with only one of the two most important elements of precautionary supply. The fact that a farmer risks to loose his delivery right as a consequence of quota under- filling is not represented in this approach.

Another problem with the application of this approach at farm-level is that the stochastic yield variation can not be observed at farm level. The production and yield of different years is observed, but it is not know which part is stochastic and which part is a consequence of choices made by the farmer (and is therefore assumed to be deterministic). E.g., the observation of an increase of yield from year A to B of 20% does not ensure that this 20% is due to weather or other stochastic effects. The farmer could also have chosen to use better land, apply more or better fertiliser, pesticides or seeds.

The abovementioned reasons have motivated us to come up with an alternative approach that is presented in next subsection.

4.2.2 Precautionary supply function

To overcome the difficulties arising with explicitly modelling yield variability and while still being able to simulate the influence of all relevant policy elements on the precautionary behaviour, we propose to calibrate precautionary C sugar beet supply that captures both elements of precautionary behaviour.

The quota and both the A and C sugar beet prices are retained as determining factors of the first element of the precautionary behaviour that come out of the approach described in previous section.

The second element of precautionary behaviour depends on the extent that farmers expect that changes, a cut or a rise, in future delivery rights will be based on past levels of sugar beet production. Building a historical references of sugar beet production and, hence, supplying C sugar beets can be seen here as a speculative strategy. According to Witzke and Kuhn (2003), a tonne of C sugar beets has a speculative value in addition to its current market value. This potential mark up depends on expectations on future prices, quotas and quota rents.

In sum, these likely complementary precautionary strategies that could rationalise together out-of-quota supply, indicate that the resulting precautionary C sugar beet supply could be captured by external factors, such as weather conditions and farm specific characteristics (soil composition, plot size, cost structure, risk aversion, under-supply penalty perception, expectations on future prices), and policy controlled parameters, such as quotas and prices that together with marginal costs determine quota rents.

Therefore, we propose to calibrate precautionary C sugar beet supply, that results from a combination of these precautionary strategies, as a function of the quota, the quota rent and farm specific characteristics.

The quota rent captures changes of the A sugar beet price, the C sugar beet price, the marginal costs and the shadow costs of limiting resources. Therefore, the precautionary supply function should be able to simulate also the impact of changes with respect to other crops on the precautionary supply of C sugar beet.

The farm characteristics can include the sugar beet grower's risk adverse behaviour, under delivery penalty perception, yield variability and plot size. The yield variability and plot size, which are probably important explaining factors, have not been taken up in the simulation model explicitly because they remain constant on a specific farm and can not be directly influenced by policy.

The model uses a farm level precautionary supply function for C sugar beets with one single calibrated parameter per farm to capture the difference in precautionary behaviour across sugar beet farms as follows:

$$x_{fc} \geq s_f \, r_f \, x_{fa} \qquad (66)$$

where:

x_{fc} is the farm supply of C sugar beets,

s_f is a farm specific precautionary supply coefficient,

r_f is the farm sugar beet quota rent,

x_{fa} is the farm supply of A sugar beets.

The farm level sugar beet profit function is then written in algebraic notation, extended with the overall land constraint (70) in matrix notation, as follows:

$$\Pi = p_{fa}\, x_{fa} + p_{fc}\, x_{fc} - q_{fs} / 2\, (x_{fa} + x_{fc})^2 - d_{fs}\, (x_{fa} + x_{fc}) \qquad (67)$$

subject to:

$$x_{fa} \leq m_f \qquad [r_f] \qquad (68)$$

$$x_{fc} \geq s_f\, r_f\, x_{fa} \qquad [\sigma_f] \qquad (69)$$

$$\sum_{f=1}^{F} \mathbf{a}_f{}'\mathbf{x}_f = \sum_{f=1}^{F} \mathbf{a}_f{}'\mathbf{x}_{fo} \qquad [l] \qquad (70)$$

where:

p_{fa} is the farm A sugar beet price,

p_{fc} is the farm C sugar beet price,

q_{fs} is the farm quadratic cost function parameter of sugar beet,

d_{fs} is the farm linear cost function parameter of sugar beet,

a_{fs} is the farm technical coefficient determining how much resource base (i.e., farmland) is needed per production quantity of sugar beet,

m_f is the farm sugar beet quota,

r_f and σ_f are the dual variables from equations (68) and (69),

l is the dual variable from the overall land constraint (70) reflecting changes in land price,

$x_{fa} \geq 0$; $x_{fc} \geq 0$; $r_f \geq 0$; $\sigma_f \geq 0$.

To ensure the equality between the dual variable from the first constraint (68) and the rent parameter in the second constraint (69), the programme is rewritten in terms of its complementary slackness conditions as follows:

$$[p_{fa} - q_{fs}\, (x_{fa} + x_{fc}) - d_{fs} - l\, a_{fs} - r_f - \sigma_f\, (\, s_f\, r_f\,)\,]\, x_{fa} = 0 \qquad (71)$$

$$[p_{fc} - q_{fs}\, (x_{fa} + x_{fc}) - d_{fs} - l\, a_{fs} + \sigma_f]\, x_{fc} = 0 \qquad (72)$$

$$[m_f - x_{fa}]\, r_f = 0 \qquad (73)$$

$$[x_{fc} - s_f\, r_f\, x_{fa}]\, \sigma_f = 0 \qquad (74)$$

$$\sum_{f=1}^{F} \mathbf{a}_f{}'\mathbf{x}_f - \sum_{f=1}^{F} \mathbf{a}_f{}'\mathbf{x}_{fo} = 0 \qquad (75)$$

The price p_{fa} and p_{fc} are available from the baseline for calibration and exogenously determined for simulation. The variables x_{fa} and x_{fc}, are the decision variables and the variables r, σ and l are the duals of the sugar quota restriction, the precautionary supply function and the overall land constraint respectively.

Equations (71) to (74) form the core model for the sugar beet activity. The overall land constraint is added because it also applies to sugar beet. The extension made for the single farm payment supplement (see Chapter 3) this sugar beet core model but is not repeated here for clarity. Within this core model, five parameters specific to the sugar beet activity need to be calibrated using observations from the baseline: q_{fs}, d_{fs}, s_f, σ_f and r_f. Because this system of equations stays underdetermined even with the additional assumption that the average cost equates the observed average costs c_{fso} of the sugar beet activity, an estimation procedure should assign these five parameters simultaneously. However, such a procedure can be quite complicated and time-consuming to develop. Therefore, one can prefer to rely on additional simplifying assumptions to approximate the sugar quota rent parameter as explained in the following section.

4.3 Quota rent approximation and sugar beet model calibration

To approximate the quota rent at the baseline, we first simplify the sugar beet activity by disregarding all C sugar beet[14]. Further, we rely on the average supply elasticity of the other arable crops to approximate simultaneously the cost function parameters of the sugar beet activity and the quota rent at farm level as follows:

$$q_{fs} = \varepsilon_f^{-1} (p_{fao} - r_f) / x_{fao} \quad (76)$$

$$d_{fs} = c_{fso} - q_{fs}\, x_{fao} / 2 \quad (77)$$

$$r_f = p_{fao} - (q_{fs}\, x_{fao} + d_{fs}) \quad (78)$$

where:

ε_f is the average supply elasticity of the farm,

c_{fso} is the observed farm average costs of sugar beet.

Figure 25 shows a large distribution of the quota rents across the sugar beet farms of the Belgian sample. The spread of the distribution in quota rents over the sample is likely to result from strong rigidities or transaction costs in the quota market as reported in Bureau *et al.* (1997). These rigidities in the quota market hamper structural adjustment in the sugar sub-sector and, consequently, lead to welfare loss (Mahler, 1994; Bureau *et al.*, 2001).

[14] Because the Belgian A quota for inuline syrup is not always filled (Commission of the European Communities, 2004b), we assume that, in contrast to A sugar, there is no quota rent for chicory and, consequently, we model chicory supply as another crop not subjected to a quota restriction.

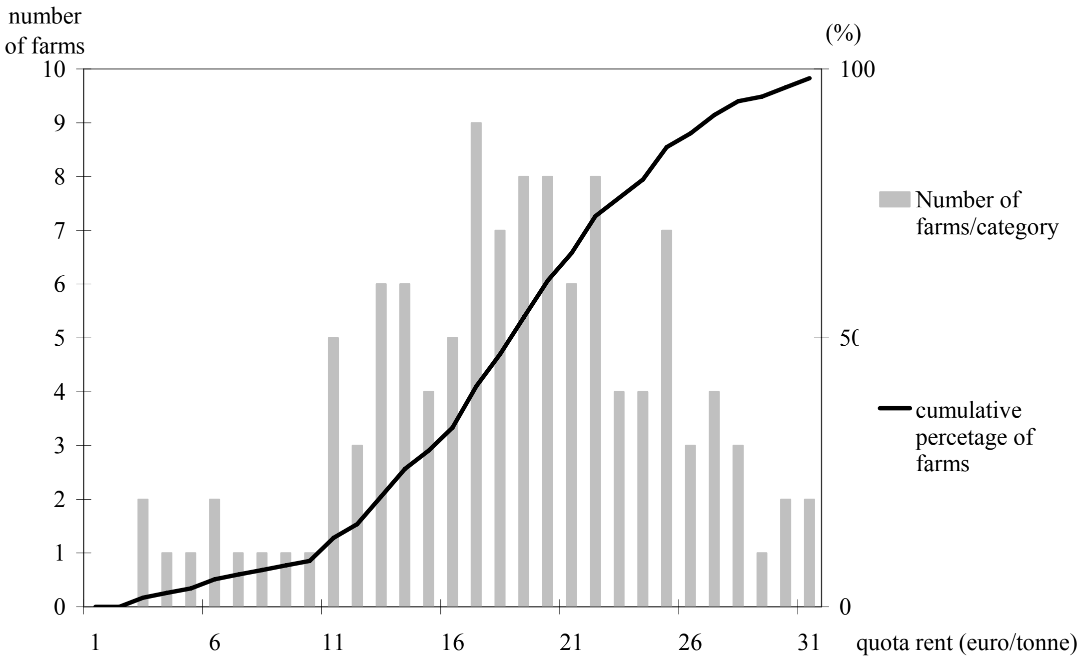

Figure 25. Distribution of the average quota rent estimates for sugar beets over the selected sample of the Belgian FADN (1995-2002)

The median calculated quota rent of about 18 euro per tonne is 20% higher than the quota rent of 15 euro that is implied in an opportunity cost for sugar beets of 30 euro per tonne derived for Belgium in 1990 by Bureau *et al.* (1997) and an average price for quota sugar beets in Belgium of about 45 euro per tonne.

The approximated quota rent is likely overestimated because the extra C sugar beet supply results in higher marginal costs. In addition, the cost of the loss made on the C sugar beet supply, σ_f, which reduces the quota rent is also not taken into account.

With the quota rent r_f now externally calibrated thanks to the use of the average supply elasticity of the farm, we can return to the core model (71) and (73) and calibrate the other parameters q_{fs}, d_{fs}, s_f and σ_f at the baseline. If, following expert opinions, we assume that C sugar beets are only supplied for precautionary purposes as explained above, the dual σ_f is strictly positive for every sugar beet farm of the sample at the baseline. Since, in addition, the dual r_f and the sugar beet supplies x_{fa} and x_{fc} are strictly positive for every sugar beet farm of the sample at the baseline, we can solve the core model for the parameters q_{fs}, d_{fs}, s_f and σ_f adding up the average cost equation to the system.

Since the values of the calibrated parameters q_{fs}, d_{fs}, s_f and σ_f largely depend on the externally calibrated quota rent r_f, a sensitivity analysis on the value of this calibrated quota rent is performed at the end of the following section.

4.4 Quota transfer

The third challenge consists in modelling the transfer of quota across sugar beet farms. Bureau *et al.* (1997), Fraser *et al.* (1997) and Mahler (1994) simulate a perfect market for quota rights but, according to Bureau *et al.* (1997), strong rigidities and transfer costs prevail within the market for sugar beet quota. These rigidities are reflected in differences among marginal costs and quota rents across farms as shown above.

Our sugar beet programme relies on a quota exchange mechanism to maximise the full use of sugar beet quotas while maintaining the possibility of differences in marginal costs across sugar beet farms of the sample. The quota exchange mechanism mimics the situation where the sugar factories have the full power to withdraw and redistribute delivery rights that are not filled.

The quota exchange mechanism operates in a loop of optimisations of the sugar beet programme presented above. After each run of optimisation of the sugar beet programme, the sugar beet quota that is eventually not filled at a particular sugar beet farm is distributed to other sugar beet farms that do fill their quota with a positive quota rent. The loop of the optimisation runs continues until the total supply of quota sugar beets reaches the total sugar beet quota available for the whole farm sample or all farms have any more a quota rent. This loop is implemented with the following simplified structure:

$$rm_{hr} = \sum_g (m_{gr} - x_{agr}) / H_r \qquad (79)$$

$$m_{gr+1} = x_{agr} \qquad \text{if } [\, r_{fr} = 0 \,] \qquad (80)$$

$$m_{hr+1} = m_{hr} + rm_{hr} \qquad \text{if } [\, r_{fr} > 0 \,] \qquad (81)$$

where:

rm is the amount of quota redistributed to each farm *h* with positive quota rent,

H is the number of farms with positive quota rent,

h indexes all farms with positive quota rent,

g indexes all farms with zero quota rent,

r indexes the run.

This quota redistribution process ends up transferring sugar beet quotas from farms with a lower gross margin on sugar beets to farms with a higher gross margin.

4.5 Calibration and simulation results

Simulations are performed on an FADN subsample of 117 Belgian sugar beet farms specialised in arable crops, each producing more than 2 ha of sugar beet. Only farm activities that account for more than 0,5% of the farm gross margin are included in the model and the simulation runs.

Table 6 illustrates the representativeness of the sugar beet farm sample with respect to its population of origin. As a result of the sample selection, the average crop and sugar beet area and the average share of sugar beet area in crop area are higher for the sample than for the population. That the average share of C sugar beet supply for the population is higher than for the sample implies that sugar beet farms growing less than 2 ha of sugar beets generally supply a higher proportion of C sugar beets that the others, strengthening our assumption about the existence of a farm specific precaution parameter.

Table 6. Comparison of sample and population for the 2002 calibration year

Farm characteristics	Sample	Population
Number of sugar beet farms	117	14 065
Average crop area per farm (ha)	52,8	40,06
Average sugar beet area per farm (ha)	10,5	6,8
Average share of sugar beet area in crop area (%)	21,7	17,0
Average sugar beet yield (T/ha)	65,7	67,7
Average share of C sugar beet supply in total sugar beet supply (%)	12,7	18,4

Sources: FADN and Belgian National Institute for Statistics

Table 7 shows the characteristics of the sample in terms of crop area share, yield and price reported by crops. Besides sugar beets, most sugar beet farms from the sample supply winter cereals, followed by fallow, potatoes, chicory and then summer cereals. The average share of area is the highest for winter cereals (27,4%), followed by potatoes (13,8%) wet pulses (10,9%) and then sugar beets (10,5%). The variability around these averages is high across the sample, in particular for potatoes. The variability around the average yields and prices is particular high for industrial and the other arable crops because these categories include diverse crops.

Table 7. Farm characteristics of the sample for the 2002 calibration year

		Area (%)		Yield (tonne/ha)		Price (€/tonne)	
Crop	# farms	average	st. deviation across farms	average	st. deviation across farms	average	st. deviation across farms
Total sugar beet	117	9,4	7,9	65,8	6,7	50,5	2,9
C sugar beet	117	1,1	0,7	65,8	6,7	11,0	1,9
Winter cereals[a]	115	27,4	19,6	8,3	0,9	105,6	15,3
Summer cereals[b]	24	5,6	4,7	6,4	1,5	108,9	31,5
Maize	11	4,1	3,1	10,7	1,6	102,6	39,1
Wet pulses	17	10,9	7,2	9,8	3,1	208,5	41,0
Potatoes	42	13,8	20,7	42,4	9,5	78,0	46,1
Chicory	40	8,1	5,1	43,2	6,1	50,2	6,8
Industrial crops[c]	4	7,3	4,9	3,9	2,9	1141,7	899,6
Other arable crops[d]	17	8,4	6,7	29,7	29,5	252,3	430,2
Fallow[e]	71	5,1	2,9	0,7	1,1	249,6	83,9

(a): includes winter wheat and winter barley, (b): includes all other cereals e.g. summer wheat, (c): includes flax and hop, (d): includes grass seeds, Belgian endive, vegetables in open air, (e): includes rapeseed, other non-food crops on fallow and set-aside.
Source: FADN

The year 2002 is chosen as the calibration year. To take the yield variations for sugar beet into account the calibration data for sugar beet are based on averages of 1995 to 2002. Table 8 reports the resulting values of the calibrated parameters of the quadratic cost function and their respective supply elasticities implied by the cost function[15].

Table 8. Calibrated cost function parameters and supply elasticities from the FADN crop farm sample

Crop	Linear cost parameter	Quadratic cost parameter	Supply elasticity	
	Average	Average	Average	St. deviation
Winter cereals	33,6	0,5	1,1	0,9
Summer cereals	34,8	3,4	1,0	0,9
Maize	16,6	2,7	1,0	0,4
Wet pulses	34,3	1,8	1,4	1,0
Potatoes	-7,2	0,1	1,3	1,1
Chicory	3,7	0,1	1,2	0,6
Industrial crops	44,4	28,9	1,1	0,2
Other arable crops	-15,8	31,3	1,1	1,5
Fallow	177,9	206,5	1,1	1,2

[15] The simulated supply elasticities can be different due to the competition for the limited resource land. Generally, the simulated supply elasticities are lower. That difference increases for crops with a larger share in the total acreage.

Simulations are based on the calibrated profit function, but with two additional decision variables for the supply of A and C sugar beets as in the profit function (67) and the sugar beet constraints (68) and (69), extended with the sample land constraint, the quota and the precautionary supply constraints, the single farm payment and the fallow constraints. This farm model is completely re-written in complementary slackness conditions in which the equality between the dual 'r_f' of the quota constraint (68) and the quota rent in equation (69) is imposed. This farm model in Mixed Complementary Problem (MCP) form is optimised with the Path solver from GAMS. After each optimisation run of the 117 farm models the equation system (79) to (81) is executed consecutively. This process is repeated until the aggregate supply of A sugar beets equal the quota available to the farm sample.

The reference scenario corresponds to the full implementation of the June 2003 CAP reform with full decoupling of direct payments for cereal, oilseed and protein (COP) crops as agreed upon in Belgium. Table 9 summarises the observed supply levels in 2002 and the simulated supply levels from the implementation of the June 2003 CAP reform. Simulation results from the reference scenario show that the implementation of the single payment with complete decoupling of COP direct subsidies leads to a decline in the supply of the previously subsidised crops such as cereals and maize, and to a supply increase of most other crops. Supply of C sugar beets increases by 18%, due to the increase in precautionary supply as a result of increased quota rents. Supply of A sugar beets is constrained by quota and, therefore, remains constant with respect to the calibration year.

Table 9. Changes in the aggregate crop supply as a result of the June 2003 CAP reform

Crop	2002 supply (tonne)	June 2003 CAP reform scenario supply (tonne)	Variation (%)
Total sugar beet	79579,4	81640,1	2,6
A sugar beet	71294,0	71294,0	0,0
C sugar beet	8285,4	10346,2	24,9
Winter cereals	25549,2	23801,2	-6,8
Summer cereals	818,8	738,2	-9,8
Maize	528,5	485,8	-8,1
Wet pulses	1772,8	2196,8	23,9
Potatoes	24506,1	27978,6	14,2
Chicory	14014,5	14014,5	0,0
Industrial crops	148,3	164,8	11,1
Other arable crops	3935,6	4325,8	9,9
Fallow	251,8	259,3	3,0

To analyse the farm effects from reforming the sugar CMO, different types of impact analyses are examined.[16] First, separately reductions in the A sugar beet price and in the sugar beet quota are simulated. Next, reductions in the A sugar beet price are combined with different reductions or increases of the quota. For the June 2005 sugar reform proposals, we also analyse the influence of different possible price compensation mechanisms. Finally, a sensitivity analysis on the quota rent parameter is performed in order to test the influence of our assumption. Results are reported in terms of percentage changes in aggregated supply and gross margin as compared with the June 2003 CAP reform reference scenario and, then, disaggregated by farm size and location.

4.5.1 Supply effects of price and quota reductions

Simulation results in Table 10 show the declining quota rents as a consequence of A sugar beet price reductions. The average quota rent remains positive for an A sugar beet price reduction of 50%. With a price cut of 30%, only 4 of the 117 sugar beet farms face a zero rent on their quota and a part of their quota is transferred to other sugar beet farms. With an A sugar beet price reduction of 50% the quota rent becomes almost zero, and as a result 37 of the 117 sugar beet farms in the sample do not fill their quota any more.

Table 10 illustrates the reductions of both total sugar beet supply and C sugar beet supply due to simulated A sugar beet price reductions. Precautionary C sugar beet supply declines sharply. The total sugar beet supply decline remains moderate because the main sugar beet supply depends on sugar beet quota. The decline in precautionary C sugar beet supply causes a drop in total sugar beet supply. Quota rents decline more sharply when there are quota transfers. Therefore, in the approach, quota transfers merely enlarge the decline of precautionary C sugar beet supply.

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[16] In simulations, price and quota variations as well as compensation mechanisms for price reductions similarly apply for chicory as for sugar beets.

Table 10. Changes in the aggregate sugar beet supply and quota rent from a reduction in A sugar beet price

A sugar beet price change (%)	A sugar beets (%)	C sugar beets (%)	Total sugar beets (%)	Quota rent (euro/tonne)
-10	0,0	-17,5	-2,2	18,5
-20	0,0	-34,9	-4,4	14,6
-30	0,0	-52,2	-6,6	10,6
-40	0,0	-69,0	-8,8	6,8
-50	0,0	-86,8	-10,8	3,2

Table 11 illustrates the impact of a sole quota reduction on the sugar beet quota rent and on the sugar beet supply. A quota reduction induces an increase of the sugar beet quota rent. The supply of C sugar beet responds positively to the quota rent increase and negatively to the A sugar beet quota reduction. The impact of the quota rent is smaller than the quota reduction resulting in a reduction of the precautionary C supply.

The total sugar beet supply reduction in Table 11 is less strong than the supply reduction induced by a quota reduction in models where a fixed precaution coefficient is applied (e.g. Frandsen *et al.*, 2003). The reduction of the precautionary supply is lower than the quota reduction, while with in other models with a fixed precautionary supply proportion the same reduction rate applies to A and C sugar beet.

Table 11 also shows that reductions in the sugar beet quota induce a much larger effect on sugar beet supply than a reduction of the A sugar beet price. The fact that a quota reduction has so much more influence on sugar beet supply than a price reduction can also be explained by observing the change in marginal revenue for both sets of scenarios. For sugar beet farms not supplying C sugar beets, a 1% reduction in the price results in a 1% decline in marginal revenue while a 1% reduction in the quota results in a more than 60% decline in marginal revenue. With a 1% price reduction, the price of the last unit supplied decreases from 50 euro to 49,5 euro, while with a 1% quota reduction the price of the last unit supplied decreases from 50 euro to less than 20 euro.

Table 11. Changes in the aggregate sugar beet supply and quota rent from a reduction in sugar beet quota

Quota change (%)	A sugar beets (%)	C sugar beets (%)	Total sugar beets (%)	Quota rent (euro/tonne)
-10	-10	-0,4	-8,8	24,9
-20	-20	-2,2	-17,8	27,5
-30	-30	-5,8	-26,9	30,2
-40	-40	-11,3	-36,4	33,0
-50	-50	-19,0	-46,0	36,0

4.5.2 Supply effects of a combined price reduction and quota reduction or increase

Figure 26 shows that the effects of a combined reduction in price and quota on sugar beet supply are much weaker than the sum of the separated effects of the reductions in price and quota. As observed in Table 10, the impact of a price reduction is larger when the quota rent decreases and reaches zero. Because the quota rent increases when quota decreases, adding a combined price reduction to a quota reduction only slightly aggravates the impact on sugar beet supply.

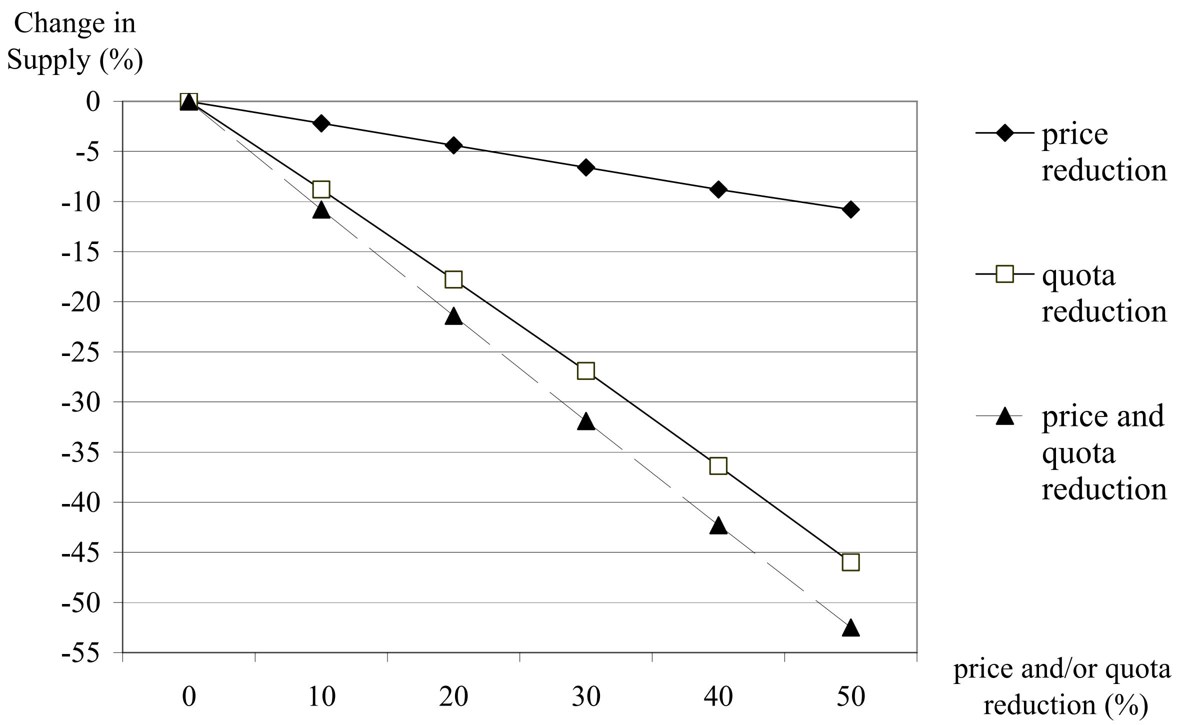

Figure 26. Effects of reductions in price and quota and their combined reductions on the aggregate supply of sugar beet

Table 7 shows the effects of an increase in sugar beet quota combined with a reduction in the A sugar beet price. This is what would happen if the Belgian sugar factories decide to buy additional quota. Such increase in quota combined with a reduction in the price induces an increase in total supply of sugar beets. As a result of the increase in available quota, sugar beet suppliers, however, shift their sugar beet production towards A sugar beets and the supply of precautionary C sugar beets declines as a result of the quota rent reduction. For a quota increase of more than 40% combined with a price reduction of more than 40%, the quota rent approaches zero. From that moment on, not the whole available quota is supplied and total sugar beet supply starts to decline.

Table 12. Changes in aggregate sugar beet supply and quota rent from changes in sugar beet quota and price

A sugar beet price change (%)	Quota change (%)	A sugar beets (%)	C sugar beets (%)	Total sugar beets (%)	Quota rent (euro/tonne)
-10	+10	10,0	-19,9	6,2	16,3
-20	+20	20,0	-42,7	12,1	10,5
-30	+30	30,0	-66,2	17,8	5,5
-40	+40	40,0	-72,9	25,7	3,6

4.5.3 Supply effects of compensation mechanisms

Figure 27 indicates the supply effects of compensating the A sugar beet price reduction with coupled and, alternatively, decoupled direct acreage subsidies in case of a 39,5% reduction in the A sugar beet price as has been agreed in November 2005 by the European Council. The compensation is calculated as the A sugar beet price reduction multiplied by the quota amount. 100% compensation can, therefore, in reality mean that farms are overcompensated because they can adjust their farm plan. The compensation is, however, as all other subsidies subject to modulation.

As expected, a coupled sugar beet subsidy mitigates the supply effect of the reduction in the price. In contrast, a decoupled sugar beet subsidy comes as an addition to the total decoupled subsidies that are granted to the farm according to its eligible area, i.e., all land not planted with potatoes and vegetables. The decoupled direct payments have, in this sample of farms, no supply inducing effect for sugar beet, because the eligible area is not the limiting factor for activating decoupled payments.

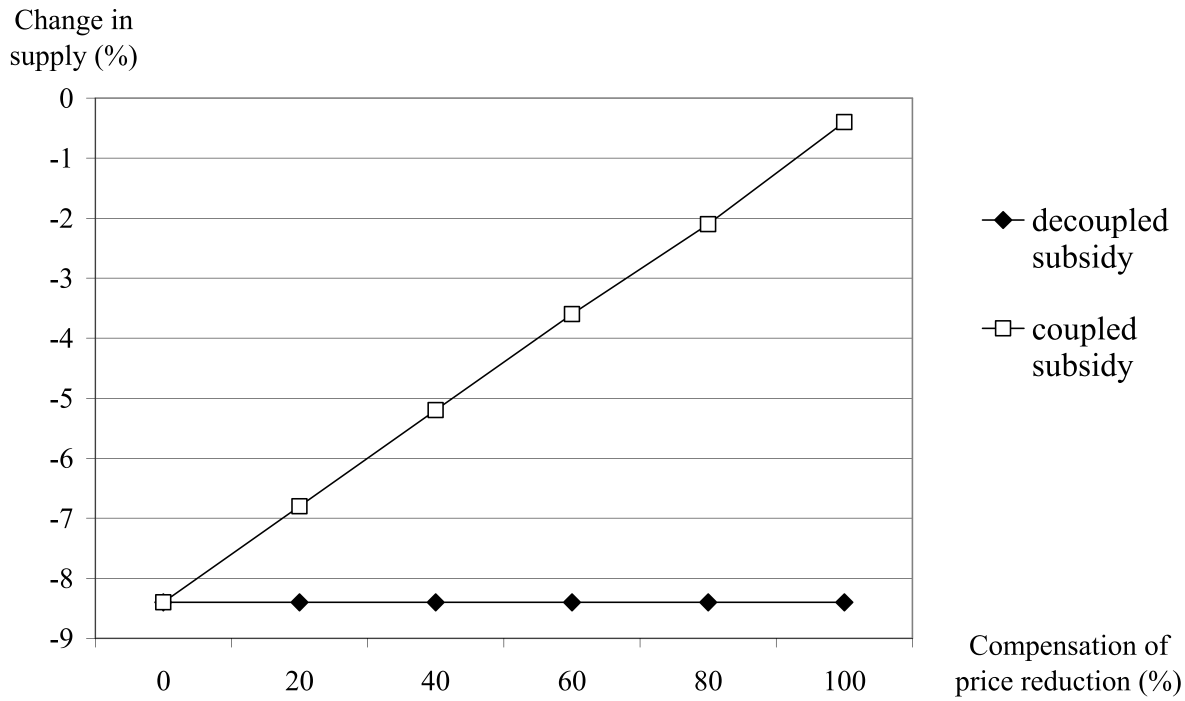

Figure 27. Effects of decoupled versus coupled compensation subsidies on the aggregate supply of sugar beets for a 39,5% reduction in A sugar beet price

4.5.4 Income effects of price and quota reductions

The income effect is another criterion for evaluating the proposed policy changes. Income effects are measured here as changes in gross margins. Figure 28 shows the effects of price and quota reductions as well as combinations of both reductions on the total gross margins aggregated over the FADN sample of the 117 sugar beet farms. Because sugar beet is currently an important and the most profitable activity among these sugar beet farms, the total gross margin is significantly affected. The aggregated total gross margin declines more sharply as a result of a reduction in price than quota.

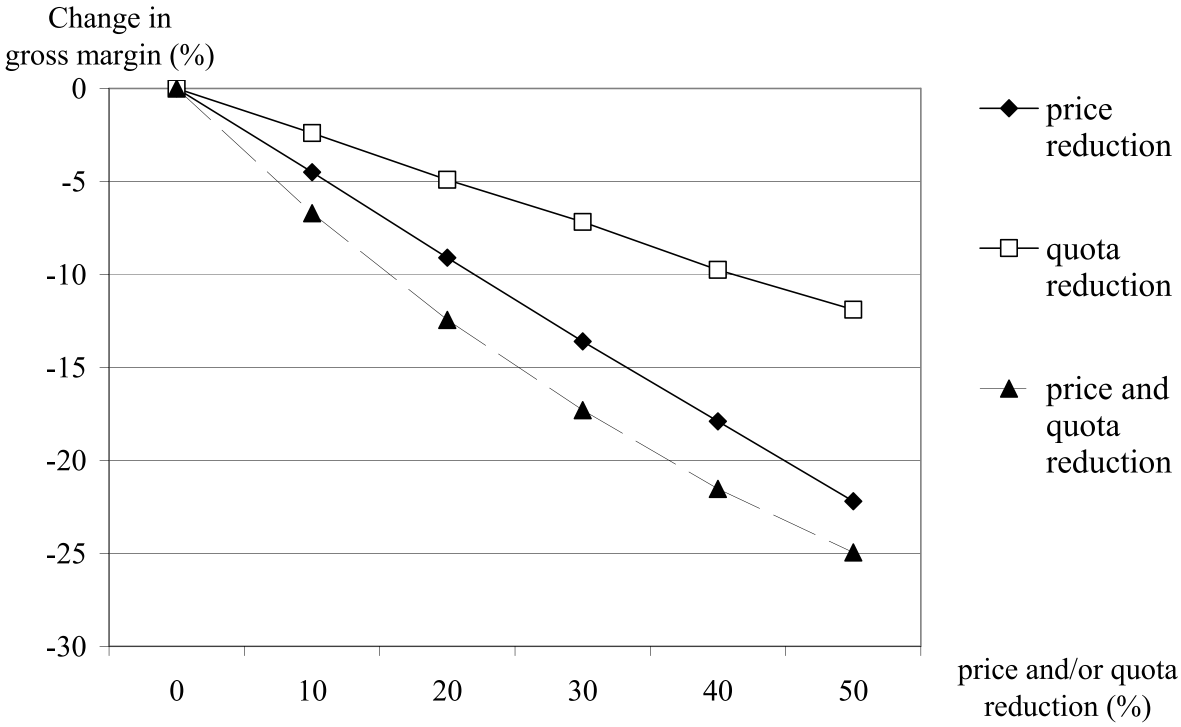

Figure 28. Effects of reductions in price and quota and their combined reductions on the aggregated total gross margin

Figure 29 shows the effects of compensating the A price reduction with coupled and, alternatively, decoupled direct acreage subsidies on the aggregated gross margin of the simulated FADN sample for a 39,5% reduction in the price. Decoupling the compensation subsidies mitigates the decline in total gross margin because, for the same amount of subsidies, sugar beet farms have more flexibility in allocating their activities to maximise their total gross margins. The difference in gross margin between coupled and decoupled subsidies is, however, very small. The simulation of the accepted EU sugar CMO reform proposal in our model induces a decline of about 8% in aggregated total gross margin.

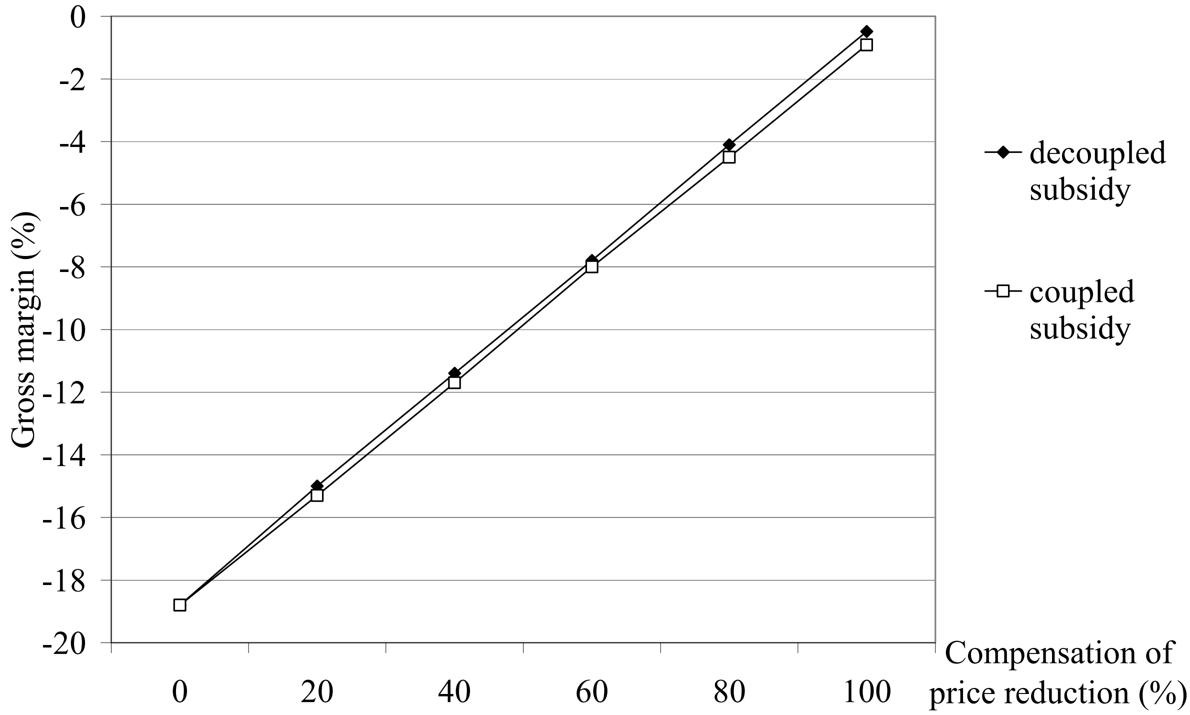

Figure 29. Effects of decoupled versus coupled price reduction compensation subsidies on the aggregated total sugar beet gross margin for a 39,5% reduction in price.

4.5.5 Supply effects on other crops

Table 13 shows to what extent a price reduction compensation, whether coupled or not, affects the supply of the other major crops of the sugar beet farms in case of a 39,5% reduction in the price and a 64,2% compensation of the price reduction. This is what is envisaged in the June 2005 proposal. As expected, a price reduction compensation coupled to sugar beet acreage has not much additional influence on the supply of the other crops. In contrast, a price reduction compensation decoupled of sugar beet acreage increases the supply of the other crops, i.e., mainly cereals, maize and potatoes.

Table 13. Effects of a price reduction compensation of 64,2% on the supply of selected crops of sugar beet farms within the Belgian FADN for a 39,5% reduction in A sugar beet price

Crop	Difference (%) Decoupled Compensation	Coupled Compensation	No compensation
Total sugar beet	-8,4	-3,3	-8,4
A sugar beet	-23,2	-3,8	-23,2
C sugar beet	0,0	0,0	0,0
winter cereals	4,9	1,4	4,9
summer cereals	3,8	1,1	3,8
Maize	1,6	0,4	1,6
wet pulses	2,2	0,6	2,2
Potatoes	2,3	0,7	2,3
Chicory	4,6	1,4	4,6
industrial crops	0,1	0,0	0,1
other arable crops	5,0	1,5	5,0
Fallow	-69,0	-27,1	-69,0

4.5.6 Supply and income effects according to farm size and region

An advantage of our farm based modelling approach is that results can be disaggregated according to certain farm characteristics such as location and farm size. Table 14 shows the model results for different farm size classes and different regions. As can be derived from the results, the supply mainly decreases on the smaller farms (L, M and S) which are mainly located in Flanders. The Flemish farms have in general more opportunities for replacing the sugar beet than the larger Walloon arable farms which have a smaller diversity of crops.

Table 14. Effects of the accepted sugar CMO reform according to size classes and regions

	Difference (%) supply	gross margin
Size classes		
XXL	-6,4	-2,5
XL	-7,4	-7,1
L	-9,3	-6,7
M	-11,8	-6,4
S	-10,9	-9,7
Regions		
Flanders	-11,3	-4,8
Wallonia	-7,5	-7,2

4.5.7 Sensitivity analysis on the quota rent approximation

Because we are aware that our approximation of the quota rent could be subject to discussion, we show the impact on the final simulation results of different assumptions of the quota rent. In the sensitivity analysis the quota rent varies from -20% to +20% of the initial value. The results are compared for three scenarios: an A sugar beet price reduction of 40%, a quota reduction of 20% and a combined price and quota reduction of 40% and 20%.

The results in Table 15 show that the impact of the varying initial quota rent on the total sugar beet supply change is limited. A change in quota rent from -20% to +20% of the initial approximation only changes the total supply reaction from -9,8% to -7,9% for the price reduction, from -16,9% to -18,3% for the quota reduction and from -25,4% to -24,9% for the combined price and quota reduction.

The most important explanation for this robustness is that the initial quota rent adjusts the precaution behaviour reversely. A higher initial quota rent leads to a lower precaution coefficient and therefore a smaller reaction of the C sugar supply to changes in quota and quota rent.

Table 15. Changes in the aggregate sugar beet supply and quota rent from A sugar beet price and quota reductions with different initial approximated quota rents

Approximated quota rent (%)	Quota change (%)	A sugar beet price change (%)	A sugar beets (%)	C sugar beets (%)	Total sugar beets (%)	Quota rent (euro/tonne)
-20	0	-40	0	-75,1	-9,8	4,2
-10	0	-40	0	-71,8	-9,3	5,5
0	0	-40	0	-69,1	-8,8	6,8
10	0	-40	0	-67,1	-8,3	7,8
20	0	-40	0	-65,9	-7,9	8,6
-20	-20	0	-20	4,0	-16,9	24,2
-10	-20	0	-20	0,5	-17,3	25,9
0	-20	0	-20	-2,3	-17,8	27,5
10	-20	0	-20	-4,5	-18,1	28,7
20	-20	0	-20	-6,0	-18,3	30,3
-20	-20	-40	-20	-60,9	-25,4	9,0
-10	-20	-40	-20	-61,0	-25,3	9,9
0	-20	-40	-20	-61,1	-25,2	10,9
10	-20	-40	-20	-61,3	-25,1	11,6
20	-20	-40	-20	-61,4	-24,9	12,4

4.6 Conclusions

4.6.1 Conclusions with respect to the application

The economic behaviour of individual sugar beet farms in Belgium who are facing delivery quota is represented in our model through an individual farm level profit function. The profit functions of sugar beet farms consists of a decision variable for the supply of A sugar beets within the delivery quota and a second decision variable for the supply of C sugar beets above delivery quota. To represent the sugar beet farms' precautionary behaviour against undersupply of their quota, a precautionary supply function is proposed. This precautionary supply function simulates changes in C sugar beet supply as a result of changes in quota and quota rent and takes the farm specific precautionary behaviour into account. From the first-order profit maximising conditions, parameters of the individual quadratic cost function of the profit function are calibrated to the base period. During simulations, individual quota rents are calculated at farm level and drive exchanges of sugar quotas from sugar beet farms with lower quota rents to sugar beet farms with higher quota rents.

Simulation results indicate that the aggregate sugar beet supply of the FADN sample is rather inelastic to a reduction in A sugar beet price, but less so to a reduction in delivery quota. These key results are in line with those obtained from the general equilibrium model of Frandsen *et al.* (2003) that simplifies the economic behaviours of sugar beet farms into one single representation per member state. However, the simulation results from the farm level approach of our model show that a quota reduction is not completely transmitted into an equivalent decline in aggregate sugar beet supply. Precautionary supply of C sugar decreases less than the equivalent quota reduction.

Adding a price reduction to a quota reduction only slightly aggravates the decline in supply from the quota reduction alone. Adding a price reduction to a quota increase generates an increase in total sugar supply, but a reduction of precautionary supply out of quota. Simulations of accepter sugar CMO reform of November 2005 that includes a 39,5% reduction in the sugar beet price and a decoupled subsidy to compensate 64,2% of the minimum sugar beet price cut reduces the aggregated sugar beet supply of the selected sample by about 8,5% and total gross margin by about 6,6%.

These simulation results have important policy implications. If the aim of the policy reform consists in reducing the Belgian sugar beet supply while preserving as much as possible sugar beet farms' incomes, then a quota reduction should be preferred to a minimum sugar beet price reduction. For example, a 10% decline in sugar beet supply requires either a quota reduction of 13% or a minimum sugar beet price reduction of 46%. In the first case, the sugar beet farms' gross margin declines by about 3% while in the second case by about 22%. However, if the aim of the policy change consists in reducing significantly the sugar market price while maintaining sugar beet supply, then a reduction in minimum sugar beet price would reach that aim, but at the expense of a considerable farm income loss. For example, a 50% reduction in minimum sugar beet price incurs a decrease in farms' gross margin of about 26%.

4.6.2 Modelling lessons

Before reflecting on modelling lessons with respect to quota, a general observation must be made to make a correct interpretation of the results possible. It should be noted that the simulation results could be sensitive to the feed-back effects from the demand side as well as the international trade effects from the expected increase in sugar imports from the least developed countries as a result of the "Everything But Arms" concessions of the EU and other challenges awaiting the EU at the current WTO round of negotiations. One avenue for further development is therefore to link this farm model to an EU and world model. Currently, the results should be interpreted rather as counterfactual for the antecedent assumptions regarding the market price than as indicative for real future observations. This shortcoming is true for most programming models in agricultural policy analysis and more specifically for all models presented in this dissertation.

With respect to quota, a fist impression is that modelling quota in MP models is straightforward, because the quota can be represented by a simple constraint. In farm-level PMP models, three challenges should nevertheless be kept in mind: quota rent approximation, the possibility for over- and undersupply and the quota transfers. With respect to these challenges, the application gives following modelling lessons.

The basic approach of quantifying the quota rent is to use observed prices for quota transactions. This approach is, of course, only useful and valid if there is a transparent market for quota and if the transactions of quota are observed. If data on quota transactions and quota prices are scarce, quota rent approximation can be complicated. The latter is true for the sugar beet in Belgium. As a consequence, the quota rent in the model is obtained by using additional assumptions, which may influence the final results. It would, therefore, be better to simultaneously calibrate all sugar beet specific parameters to avoid the ad hoc assumptions related to the quota rent. The sensitivity analysis has shown, however, that the results are quite robust regarding different quota rent assumptions.

The possibility of oversupply is captured by a precautionary supply function. The application has shown that the model simulates more flexible the impact of policy changes than models with a fixed precaution behaviour (such as Frandsen *et al.*, 2003). The precautionary supply function and the cost function are, however, probably not yet flexible enough to capture all elements of farm behaviour. The cost function has only two calibrated parameter per crop per farm and the only interaction between crops is simulated through the common constraints such as land and direct payments. The precautionary supply function has only one parameter and the model, therefore, imposes a linear relationship between quota rent and C sugar beet supply. The estimation of more complex flexible functions requires, however, more data and more adequate estimation techniques.

Next chapter is devoted to an EMP approach to tackle the issues of quota rent approximation and the calibration of a more flexible precautionary supply function.

The third challenge is the modelling of quota transfers. Quota transfers are driven by farm heterogeneity and hampered by transaction costs. SEPALE incorporates the farm heterogeneity through the farm-level optimisation, but little known on the transactions costs of transfers of quota. Further research is needed to assess these transaction costs and incorporate them in the model because they can be important for policy recommendation and they can influence the results.

Chapter 5 EMP extension of SEPALE

Chapter 5 elaborates on EMP with an application of EMP to the sugar module developed in previous chapter. EMP refers to a calibration process in which the first-order conditions have non-zero degrees of freedom, in contrast to PMP where there are zero degrees of freedom. The purpose of the application is to calibrate the parameters of the sugar module based on an estimation procedure. The estimation procedure avoids that ad hoc assumptions have to be made and makes it possible to use a more flexible functional form for the precautionary supply function.

There are, however, different definitions and connotations for the terms calibration and estimation. Therefore, before the presentation of application, the chapter first reflects on the meaning of estimation and calibration and how they are used in the context of this dissertation.

Chapter 5 also presents more detailed results on the sugar reform, based on different reactions of 4 farm groups of the same sample used in Chapter 4. These farm groups are identified with a cluster analysis established with quota rent and percentage C supply as base variables.

Parts of this chapter have been submitted as

Buysse, J., Fernagut, B., Harmignie, O., Henry de Frahan, B., Lauwers, L., Polomé, P., Van Huylenbroeck, G. and Van Meensel, J. (2006). Farm based modelling of the EU sugar reform: impact on Belgian sugar beet suppliers. Submitted.

5.1 Introduction

Instead of relying on an auxiliary LP program and on additional assumptions, apparent in most PMP applications, Heckelei and Wolff (2003) suggest an alternative by the estimation of a programming model based on its first-order optimality conditions. This approach, which is called in this dissertation EMP (Buysse *et al.*, 2006), is used to calibrate the sugar module of our model. Before presenting the application, the introduction gives an overview of different opinions on the meaning and the use of calibration and estimation in this case.

In the literature, there is no consensus on the definition and use of estimation and calibration. Quah (1995) makes following caricature of the difference between calibrators and estimators. Calibrators criticises standard econometric practices for being uninformative on important questions and have chosen to use calibration as an alternative to standard statistical estimation. They have chosen to apply not the standard diagnostic testing, but to use a model's operating characteristics to evaluate it. Estimators evaluate models using statistical or aesthetic criteria unmotivated by economic reasoning.

Also Balistreri and Hillberry (2005), state that the distinction in connotation between calibration and estimation originates from the different focus of the research. They delineate the processes of model fitting to the data and the subsequent model analyses. The different respective notions of calibration and estimation only become clear in the analysis of fitted models as the degree of concentration on counterfactual simulation versus hypothesis testing.

Although there seems to be acrimony between calibrators and estimators (Quah, 1995), the approaches are sometimes very alike, certainly in the stage of model fitting. E.g., Dawkins *et al.* (2001) state with respect to model fitting: "Calibration is estimation, estimation is calibration", a point which is widely recognized in the macroeconomic real-business-cycle literature (Hoover, 1995). Both calibration as estimation fit model to data (Balistreri and Hillberry, 2005). The terms calibration and estimation have, furthermore, technical meanings that are sufficiently general that each could contain the other (Quah, 1995).

According to these different views on calibration and estimation, which mainly come from the literature of real business cycle economics, the approach introduced by Heckelei and Wolff (2003), 'estimation of constrained optimisation models' also belongs to the branch of calibrated models because of the focus on model fitting instead of hypothesis testing. The same holds for all MP approaches presented in this dissertation.

The difference that we make between PMP and EMP could, therefore, be subject to discussion. We define PMP and EMP models as follows.

The parameters of both PMP and EMP models are chosen to guarantee that the model precisely mimics some particular feature of the historical data and, as a consequence, both PMP and EMP models are calibrated.

According to our definition, a model belongs to the class of PMP models when its parameters are assigned from the optimality conditions with zero degrees of freedom. In case of non-zero degrees of freedom additional parameters are quantified from casual empiricism or unrelated econometric studies or simplifying assumptions.

Conversely, the optimality conditions of an EMP model do not have zero degrees of freedom and, therefore, a minimisation algorithm is used to adjust the simulation model's parameters such that the simulated output deviates minimally from the real output.

The definitions used in this dissertation and in Buysse *et al.* (2006) do also not completely correspond to other definitions. E.g., Heckelei and Britz (2005) define the use of phase 1 of a defining character of PMP and call the newly developed approaches 'alternative approaches to calibration and estimation or programming models'. According to that definition, Judez *et al.* (2001) and SEPALE are no PMP methods, while they have been published as PMP variants. For that reason, and to make the difference with EMP a bit clearer, we have chosen to use a broader definition for PMP than Howitt (1995a) and Heckelei and Britz (2005).

More important than the definition, the differences and similarities between different modelling approaches PMP and EMP should become clear. To illustrate the differences between PMP and EMP, the remainder of the chapter presents an EMP version of the sugar module of SEPALE.

5.2 Application: estimation of the C sugar beet precaution supply function

Previous chapter has concluded with the need for a simultaneous estimation of the optimality conditions of the sugar module. This estimation has two advantages. First, the simplifying assumptions for calibration are not needed anymore and the estimation allows for a more flexible functional form of the precautionary supply function.

In the EMP version of the sugar module, we propose therefore a quadratic functional form of the farm level precautionary supply function for C sugar beets as a function of the quota rent with calibrated parameters s0 and s1 per farm to capture the difference in the precautionary behaviours across sugar beet farms as follows:

$$x_{fc}/x_{fa} \geq s0_f\, r_f + s1_f\, r^2_f \qquad (82)$$

where:

$s0_f$ is a farm specific precautionary supply coefficient,

$s1_f$ is a farm specific precautionary supply coefficient,

The programme in terms of its complementary slackness conditions is as follows:

$$[p_{fa} - q_{fs}\,(x_{fa} + x_{fc}) - d_{fs} - l\, a_{fs} - r_f - \sigma_f\,(s0_f\, r_f + s1_f\, r^2_f\,)]\; x_{fa} = 0 \qquad (83)$$

$$[p_{fc} - q_{fs}\,(x_{fa} + x_{fc}) - d_{fs} - l\, a_{fs} + \sigma_f]\; x_{fc} = 0 \qquad (84)$$

$$[m_f - x_{fa}]\; r_f = 0 \qquad (85)$$

$$[x_{fc}/x_{fa} - s0_f\, r_f - s1_f\, r^2_f]\; \sigma_f = 0 \qquad (86)$$

$$\sum_{f=1}^{F} \mathbf{a}_f\mathbf{'x}_f - \sum_{f=1}^{F} \mathbf{a}_f\mathbf{'x}_{fo} = 0 \qquad (87)$$

Within this core model, six parameters specific to the sugar beet activity need to be calibrated using observations from the baseline: q_{fs}, d_{fs}, $s0_f$, $s1_f$, σ_f and r_f. The procedure to estimate these unknown parameters is based on the approach proposed by Heckelei and Wolff (2003) and is presented in next subsection.

Heckelei and Wolff (2003) have used Generalized Maximum Entropy (GME) (Golan *et al.*, 1996), but they acknowledge that for their application, Ordinary Least Squares (OLS) could have been applied as well. We have also chosen to apply GME, because Golan *et al.* (1996; p. 192 - 200) show, with preliminary sampling experiments, that the GME-data formulation has lower MSE than other estimators for a simultaneous equations estimation as in this case. In addition, GME allows for nonlinear relationships in parameters in the model. GME has, however, three disadvantages for this application.

The first disadvantage is that GME offers fewer possibilities for performing statistical tests than traditional econometric techniques such as OLS. While test statistics could add to the utility of the entropy approach, it should be noted that the philosophy of the entropy estimation approach within such a framework does not heavily emphasises hypothesis testing. The focus is on using all available information to estimate and calibrate the unknown parameters of the programming model. Once these parameters are obtained, based on all available information from theory, data, and prior experience in the estimation procedure, information theory dictates to use all, significant or not, the parameter estimates in the simulation model. Doing anything else would imply the existence of additional information - a possibility that has already been ruled out (Arndt *et al.*, 2002).

The second disadvantage is that there is no closed form solution for the estimation. Heckelei and Britz (2005) describe computational problems that can be expected from a GME estimation of equations (83) to (87). A first possible solution is to use the Mathematical Programming with Equilibrium Constraints (MPEC) solver in GAMS, which is still in development. For the estimation of the sugar beet module in Belgium, it is easier to make in advance the assumptions that the quota constraint (68) and the precautionary supply constraint (82) are binding, which are important computational simplifications (for more details on the computational problems see Heckelei and Britz, 2005).

The third disadvantage of GME is the need of support point intervals for the estimated parameters and errors that can introduce a possible bias in the estimation results. The following three courses of action can minimize the impact of the support points on the results. First, a number of parameters and equations are eliminated by substitution. Second, we impose a common parameter d across the sample. Third, very wide support ranges for the estimated parameters reduce the influence of the centre of the support interval on the obtained result.

The estimation is performed on unbalanced panel data of the same sample of 117 farms that have been used in Chapter 4, with observations from 1995 to 2003. We assume that the farm technology is captured by its cost function (parameters d and q) and that technology remains constant for each individual farm. Therefore, q and d are time independent. q is farm dependent to capture differences in technology between farms and d is common across the sample to capture the common part of the technology[17]. The farms have the possibility to supply a different quantity of sugar beet in the different years (changes on the marginal cost function). This variation of quantities results in changes of marginal costs and quota rents, which are, therefore, farm and time dependent. Finally, the precaution function parameters s0, s1 are chosen to be farm dependent but invariant in time.

The choice of support points and the complexity of the estimation are simplified by the elimination of the parameter q and σ in the system of equations as follows:

$$pa_{f,t} - 2\, co_{f,t} + d - r_{f,t} + (pc_{f,t} - 2\, co_{f,t} + d)\,(s0_f\, r_{f,t} + s1_f\, r_{f,t}^2) = 0 \tag{88}$$

$$xc_{f,t} - s0_f\, r_{f,t}\, m_{f,t} - s1_f\, r_{f,t}^2\, m_{f,t} = 0 \tag{89}$$

In order to capture the weather effects on the supply of C sugar beet, the parameter w_t and year dummies T_t are added to the precautionary supply function. Together with two error terms, following estimation equations are proposed:

$$pa_{f,t} - 2\, co_{f,t} + d - r_{f,t} + (pc_{f,t} - 2\, co_{f,t} + d)\,(s0\, r_{f,t} + s1_f\, r^2_{f,t}) + e1_{f,t} = 0 \tag{90}$$

$$xc_{f,t} / m_{f,t} - s0_f\, r_{f,t} - s1_f\, r^2_{f,t} + w_t\; T_t + e2_{f,t} = 0 \tag{91}$$

[17] It is more common in panel estimation to assume a common slope 'q' instead of a common intercept 'd'. However, with a farm independent parameter 'q' across the sample, we impose that supply elasticities 'ε' vary extensively among farms as a consequence of large differences in supplied quantities among farms in the sample (elasticity = 1/q * price/quantity). An additional motivation to choose a common parameter 'd' instead of a common parameter 'q', is that a common parameter 'q' mathematically leads to lower rents and a lower elasticity on larger farms than smaller farms. A common parameter 'd' does not impose any differences on rents or elasticities that depend on structural differences among farms.

To obtain a calibrated model, additional restrictions prevent negative quota rents, a decreasing marginal cost function and a decreasing precautionary supply as a function of the quota rent. The GME estimation is performed as proposed by Golan *et al.* (1996). We estimate unobserved frequencies pd_k, $pr_{k,f,t}$, $ps0_{k,f}$, $ps1_{k,f}$, $pe1_{k,f,t}$, $pe2_{k,f,t}$, $pw_{k,t}$ that represent the data generating process of respectively d, $r_{f,t}$, $s0_f$, $s1_f$, $e1_{f,t}$, $e2_{f,t}$, w_t. Therefore, we have to define the support points zd_k, $zr_{k,f,t}$, $zs0_{k,f}$, $zs1_{k,f}$, $ze1_{k,f,t}$, $ze2_{k,f,t}$ and $zw_{k,t}$ of the parameters $r_{f,t}$, $s0_f$, $s1_f$, $e1_{f,t}$, $e2_{f,t}$ and w_t respectively. The number of support point, k, for each parameter and error term is 2. The support intervals for the parameters are [-1000;1000] for d and r and [-100;100] for s0, s1, and w, and [-40;40] for e1 and [-0,5;0,5] for e2.

The estimation is executed with GAMS software and the CONOPT solver as follows:

$$\text{Max } H = - \textstyle\sum_k pd_k \ln(pd_k) - \sum_{k,f,t} pr_{k,f,t} \ln(pr_{k,f,t}) - \sum_{k,f} ps0_{k,f} \ln(ps0_{k,f}) - \sum_{k,f} ps1_{k,f} \ln(ps1_{k,f})$$
$$- \textstyle\sum_{k,f,t} pe1_{k,f,t} \ln(pe1_{k,f,t}) - \sum_{k,f,t} pe2_{k,f,t} \ln(pe2_{k,f,t}) - \sum_{k,f} pw_{k,t} \ln(pw_{k,t}) \quad (92)$$

subject to :

$$pa_{f,t} - 2\, co_{f,t} + d - r_{f,t} + (pc_{f,t} - 2\, co_{f,t} + d)\,(s0_f\, r_{f,t} + s1_f\, r^2_{f,t}) + e1_{f,t} = 0$$
$$xc_{f,t} / m_{f,t} - s0_f\, r_{f,t} - s1_f\, r^2_{f,t} + w_t\, T_t + e2_{f,t} = 0$$
$$s0_f\, m_{f,t} + 2\, s1_f\, r_{f,t}\, m_{f,t} > 0$$
$$d < co_{f,t}$$
$$d = \textstyle\sum_k zd_k\, pd_k$$
$$r_{f,t} = \textstyle\sum_k zr_{k,f,t}\, pr_{k,f,t}$$
$$s0_f = \textstyle\sum_k zs0_{k,f}\, ps0_{k,f}$$
$$s1_f = \textstyle\sum_k zs1_{k,f}\, ps1_{k,f}$$
$$e1_{f,t} = \textstyle\sum_k ze1_{k,f,t}\, pe1_{k,f,t}$$
$$e2_{f,t} = \textstyle\sum_k ze2_{k,f,t}\, pe2_{k,f,t}$$
$$w_t = \textstyle\sum_k zw_{k,t}\, pw_{k,t}$$
$$1 = \textstyle\sum_k pd_k$$
$$1 = \textstyle\sum_k pr_{k,f,t}$$
$$1 = \textstyle\sum_k ps0_{k,f}$$
$$1 = \textstyle\sum_k ps1_{k,f}$$
$$1 = \textstyle\sum_k pe1_{k,f,t}$$
$$1 = \textstyle\sum_k pe2_{k,f,t}$$
$$1 = \textstyle\sum_k pw_{k,t}$$

Table 16 presents some average values and standard deviation of the resulting estimated parameters. The average value of the quota rent en the cost function imply that the cost function for sugar beet is flatter than for other crops.

The average value of the precaution parameters s0 and s1 are both negative. The average percentage of C sugar beet is, however, positive on every farm. This implies that s1 is more negative on farms with a low quota rent and s0 is more negative on farms with a higher quota rent. The standard deviation of s0 and s1 show that there is much variation in the precautionary behaviour among farms.

Table 16. Key results of the estimation of the sugar module

Parameter	**average**	**st. deviation**
r	20,4	7,8
d	8,58	0
s0	-0,059	0,33
s1	-0,0022	0,075

Figure 30 shows the distribution of the resulting estimated average quota rents across the sugar beet farms of the Belgian sample.

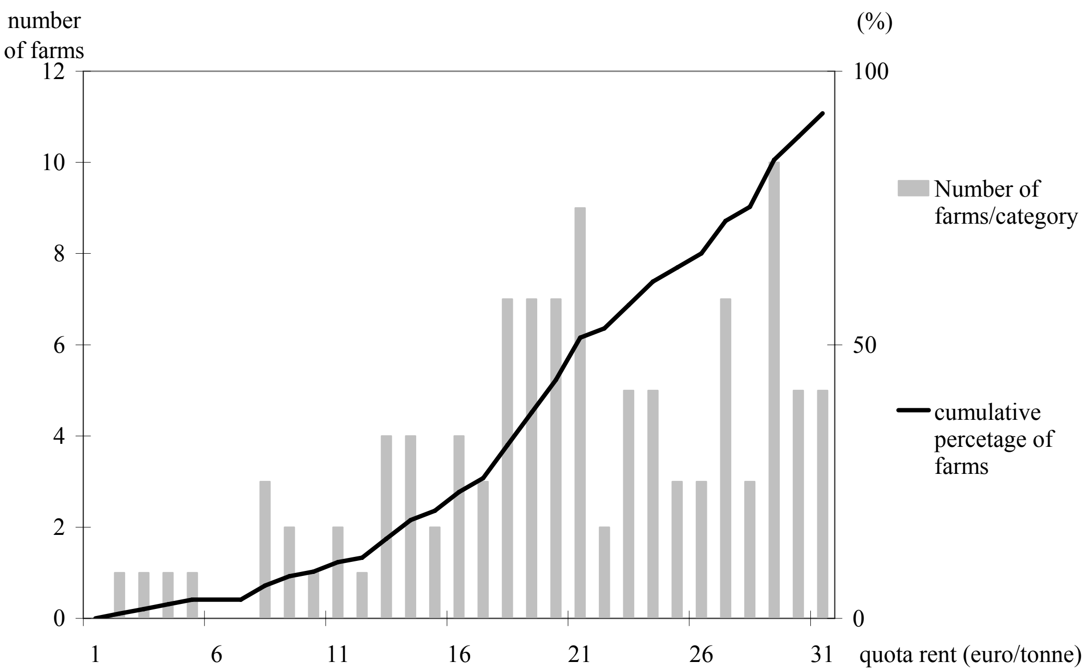

Figure 30. Distribution of the approximated average quota rents for sugar beets over the selected sample of the Belgian FADN (1995-2002)

The median calculated quota rent of about 20 euro per tonne is higher than the approximated quota rent of 18 euro of the PMP application. The main reason is that the estimated cost function is flatter than the PMP approximation.

A sensitivity analysis reported in Table 17 of the support intervals shows that the parameter estimates 'd_s', 'q_{sf}' and 'r_f' are robust with respect to the choice of the support intervals. Conversely, the average values of the parameter estimates '$s0_f$' and '$s1_f$' are quite sensitive to different support intervals due mainly to multicollinearity between ρ_{ft} and ρ^2_{ft}.

Table 17. GME parameter estimates of the sugar beet programme from a sensitivity analysis on the support intervals

Intervals		r_f	d	q_f	$s0_f$	$s1_f$
Narrower support intervals for the parameters: [-100;100] for d and $r_{f,t}$, and [-10;10] for $s0_f$, $s1_f$ and w_t	Average	16,0	8,00	0,027	-0,016	-0,002
	St. deviation	6,8	0,00	0,091	0,140	0,046
Wider support intervals for $e2_{f,t}$: [-1;1]	Average	20,6	8,58	0,025	-0,028	0,002
	St. deviation	7,6	0,00	0,085	0,150	0,007
Wider support intervals for $e1_{f,t}$: [-80;80]	Average	19,9	8,58	0,025	-0,052	0,009
	St. deviation	7,9	0,00	0,085	0,530	0,031

5.3 Calibration and simulation results

The same reference scenario of the PMP application in Chapter 4 is used. Table 9 summarises the observed supply levels in 2002 and the simulated supply levels from the implementation of the June 2003 CAP reform. Supply of C sugar beets increases here by 54%, which is higher than the 18% of the PMP application. On most farms this is due to the increase in precautionary supply as a result of increased quota rents. On three farms, however, the decrease of the land rent makes C sugar beet supply profitable. Due to the flat cost function for sugar beet and the A sugar beets quota, the C sugar beet supply increases very much. The increase of total sugar beet supply is, nevertheless, lower than the increase of supply of wet pulses, potatoes and industrial crops.

Table 18. Changes in the aggregate crop supply as a result of the June 2003 CAP reform

Crop	2002 supply (tonne)	June 2003 CAP reform scenario supply (tonne)	Variation (%)
Total sugar beet	89168,0	97649,8	9,5
A sugar beet	78895,2	78895,2	0,0
C sugar beet	10272,8	18754,6	82,6
Winter cereals	25549,2	23134,2	-9,5
Summer cereals	818,8	717,5	-12,4
Maize	528,5	476,2	-9,9
Wet pulses	1772,8	2173,8	22,6
Potatoes	24506,1	27784,1	13,4
Chicory	14014,5	14014,5	0,0
Industrial crops	148,3	163,9	10,5
Other arable crops	3935,6	4303,9	9,4
Fallow	251,8	255,6	1,5

5.3.1 Identification of farm groups

One of the advantages of farm-level modelling is that results can be differentiated according to farm type. To show the impact on different types of farms and to illustrate the underlying economic mechanisms driving the aggregated outcome, four farm groups are identified with a k-means cluster analysis[18]. The cluster analysis is based on two variables of importance for the changes in sugar beet supply, the quota rent and percentage of C sugar beet supply. The farm segregation is reported in Figure 31.

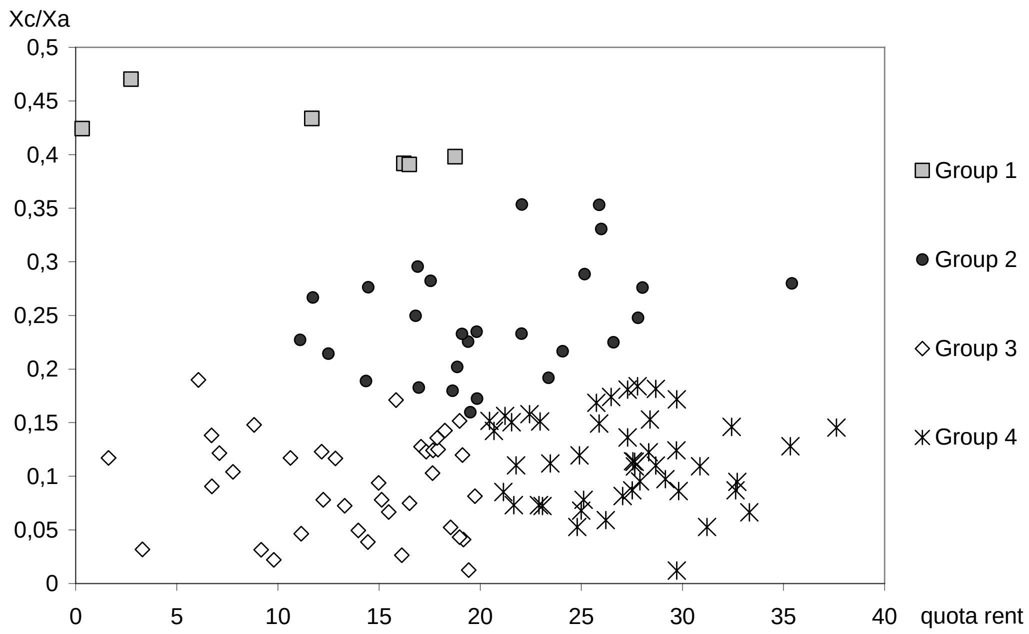

Figure 31. Farm segregation from a k-means cluster analysis based on the quota rent and the percentage C sugar supply

Group 1 represents 6 farms with a low quota rent and a high percentage of C sugar beet supply in the total sugar beet supply. Table 19 indicates that the farms of group 1 are equally divided over the Walloon region and the Flemish region. Table 20 shows that the farms in group 1 have on average 29,2 ha, which is the smallest of the 4 farm groups.

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[18] To perform a k-means cluster analysis, one has to specify the number of clusters and optionally the centres of the clusters (otherwise they are randomly initialised). Each observation in the data set is then assigned to a cluster based on its smallest Euclidian distance to the cluster centre. After the complete data set is assigned, new cluster centres are calculated as the average positions of the data points within each cluster. This process of assigning and averaging is repeated until the cluster centres converge. The cluster analysis is executed on standardised variables.

Group 2 represents 27 farms with a higher quota rent than group 1 and a high percentage of C sugar beet. The farms of group 2 are mainly located in the Walloon region. The farms of group 2 are, with 39,9 ha, larger than the farms of group 1.

The high percentage of C sugar beet indicate that groups 1 and 2 are more risk averse with respect to quota under filling than the farms in group 3 and 4. This risk averse behaviour is also reflected in the lower acreage of potatoes, a crop with a high gross margin but with volatile yields and prices.

Group 3 consists of primarily Flemish farms with the lowest quota rent and percentage C sugar beet supply. The 38 farms of group 1 cultivate on average 52,6 ha, of which 9 ha is allocated to potatoes.

The largest group 4, with 46 farms, contains mainly Walloon farms with a high quota rent and a low percentage C sugar beet supply. The farms of group 4 are the largest, with 66.7 ha, and are, more than the farms of the other groups, also involved with chicory production.

The Flemish farms can for the most part be found in the farm groups with a lower quota rent, 1 and 3. The lower rent at these farms can be explained by the larger acreage of crops with a high gross margin and the higher land price than at the farms in group 2 and 4.

Table 19. Distribution of the farms over the different regions

Region	Group 1	Group 2	Group 3	Group 4
FLPO	1	1	6	2
FLCA	0	0	1	0
FLSL	1	1	8	2
FLLO	1	1	6	1
Flemish region	**3**	**3**	**21**	**5**
WASL	0	3	1	6
WALO	2	16	11	28
WACO	1	5	3	5
WAHL	0	0	0	1
WAFF	0	0	2	1
Walloon region	**3**	**24**	**17**	**41**
Total	**6**	**27**	**38**	**46**

Table 20. Average acreage of different crops for the 4 farm groups (in ha)

Crop	Group 1	Group 2	Group 3	Group 4
Total sugar beet	6,7	9,0	11,1	14,3
A sugar beet	4,7	7,2	10,2	12,8
C sugar beet	2,0	1,8	0,8	1,4
Winter cereals	17,4	23,1	23,3	33,4
Summer cereals	0,0	1,4	0,8	1,4
Maize	0,0	0,0	0,6	0,5
Wet pulses	0,0	0,0	1,1	3,1
Potatoes	1,5	1,1	9,0	4,3
Chicory	0,7	1,6	1,2	5,1
Industrial crops	0,7	0,0	0,7	0,0
Other arable crops	0,6	0,9	1,8	1,1
Fallow	1,6	2,7	3,0	3,6
Total	**29,2**	**39,7**	**52,6**	**66,7**

Table 21 gives an overview of the differences precautionary behaviour between the four farm groups. The farms of group 1 and 2 have a steep precautionary supply as function of the quota rent. That function is concave for group 1 and convex for group 2. The precautionary supply function of group 3 and 4 is also convex but flatter that the functions of group 1 and 2.

Table 21. Average precaution parameters for the 4 farm groups

	Group 1		Group 2		Group 3		Group 4	
	average	st. deviation	average	st. deviation	average	st. deviation	average	st. deviation
s0	0,30	0,57	-0,24	0,54	-0,0039	0,021	-0,047	0,15
s1	-0,13	0,29	0,015	0,034	0,0011	0,0013	0,0020	0,0064

In the following sections, results are shown for the different farm groups as well as the aggregated results of the sample. To analyse the farm effects from reforming the sugar CMO, different types of impact analyses are examined.[19] First, separately reductions in the A sugar beet price and in the sugar beet quota are simulated. Next, reductions in the A sugar beet price are combined with different reductions or increases of the quota. For the sugar CMO reform, we also analyse the influence of different possible price compensation mechanisms. Results are reported in terms of percentage changes in supply and gross margin as compared with the June 2003 CAP reform reference.

[19] In simulations, price and quota variations as well as compensation mechanisms for price reductions similarly apply for chicory than for sugar beets.

5.3.2 Supply effects of price and quota reductions

Simulation results in Figure 32 show the transfers of quota as a consequence of A sugar beet price reductions. The quota rent remains positive at every farm for an A sugar beet price reduction of 30%. With a price cut of more than 30%, a number of farms in group 3 do not fill completely their quota anymore and, as a consequence, the quota are transferred to the other farms. Farms mostly belonging to group 2 and 4 profit from those quota transfers to increase their quota.

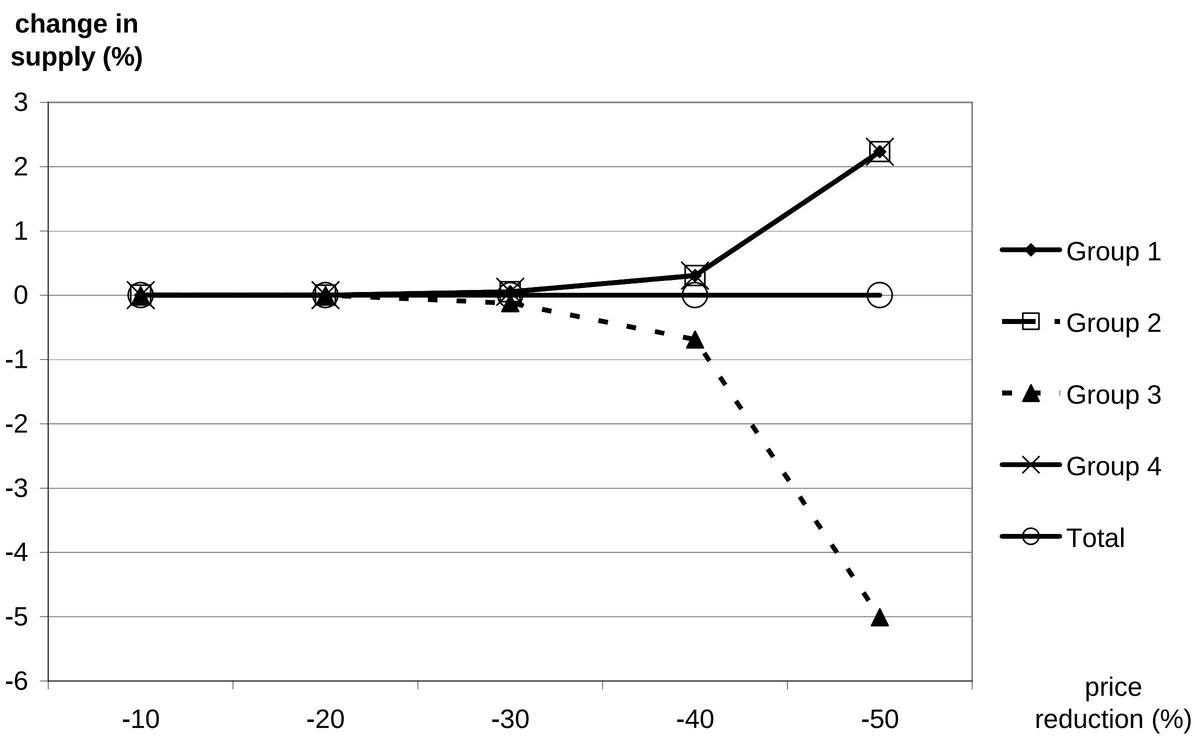

Figure 32. Effects of reductions in price on the supply of quota sugar beet of the 4 farm groups

Figure 33 and Figure 34 illustrate the reductions of C sugar beet supply and the total sugar beet supply respectively from simulated A sugar beet price reductions for the different farm groups. The price cuts reduce the quota rents and, therefore, precautionary C sugar beet supply declines at all farms. However, the additional quotas for some farms, at price reductions of more than 30%, compensate partially the precautionary supply reduction induced by the decrease in quota rent. Therefore, especially the decline of precautionary supply in groups 2 and 4 slows down for increasing price reductions.

Farms with a concave precautionary supply as a function quota rent, situated in group 1, have a convex declining supply as a function of declining prices. Farms with a convex precautionary supply as a function quota rent, situated in groups 2, 3 and 4, have a concave declining supply as a function of declining prices.

The total sugar beet supply declines moderately, because the sugar beet supply mainly depends on sugar beet quota. There are, however, differences between the farm groups. For a moderate price reduction, the impact on the supply for the different farm groups is very similar because they all reduce their precautionary C sugar beet supply as a result of declining quota rents. Farms with the lowest percentage of precautionary supply, situated in group 3, are the least affected in their total sugar beet supply.

For larger A sugar beet price reductions, the quota transfers play an important differentiating role. The decline of sugar beet quota of farms in group 3 is added to the decline in precautionary sugar beet, causing a drop in total sugar beet supply. Conversely, in groups 2 and 4, quota transfers mitigate the reduction of precautionary C sugar beet supply. Therefore, the total sugar beet supply of farms in group 2 and 4 is higher for a price reduction of 50% than for a price reduction of 30% (see Figure 34).

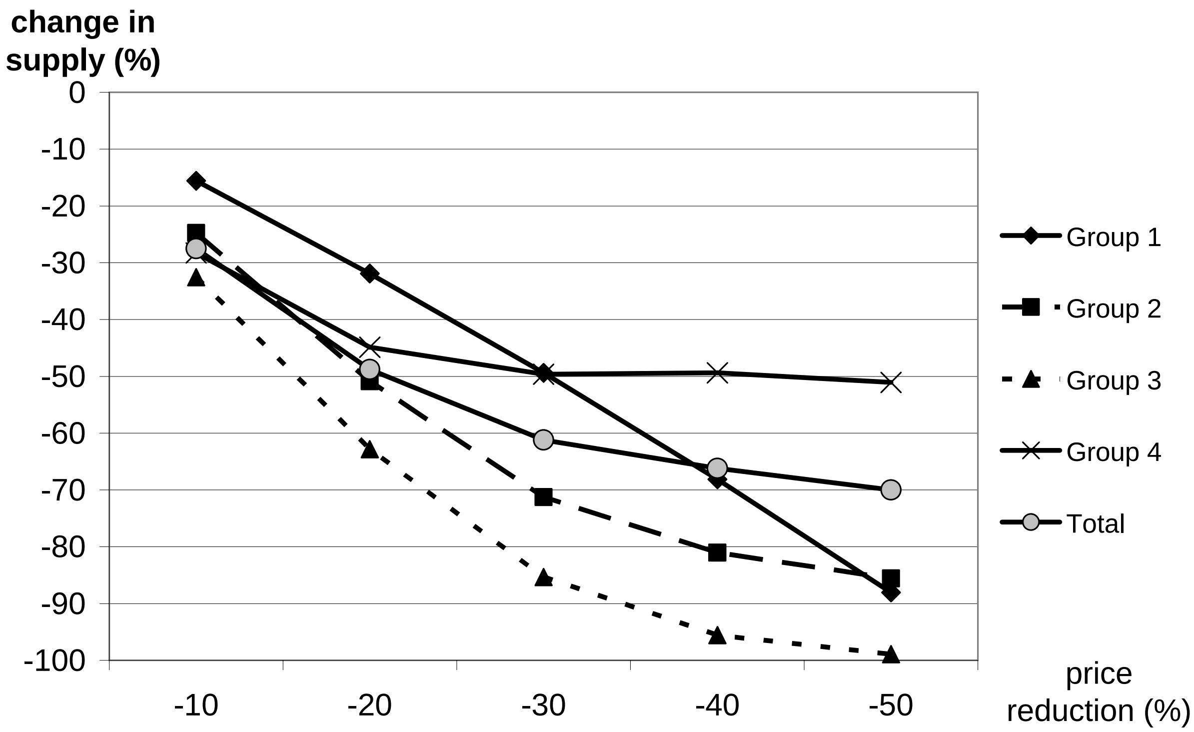

Figure 33. Effects of reductions in price on the supply of C sugar beet of the 4 farm groups

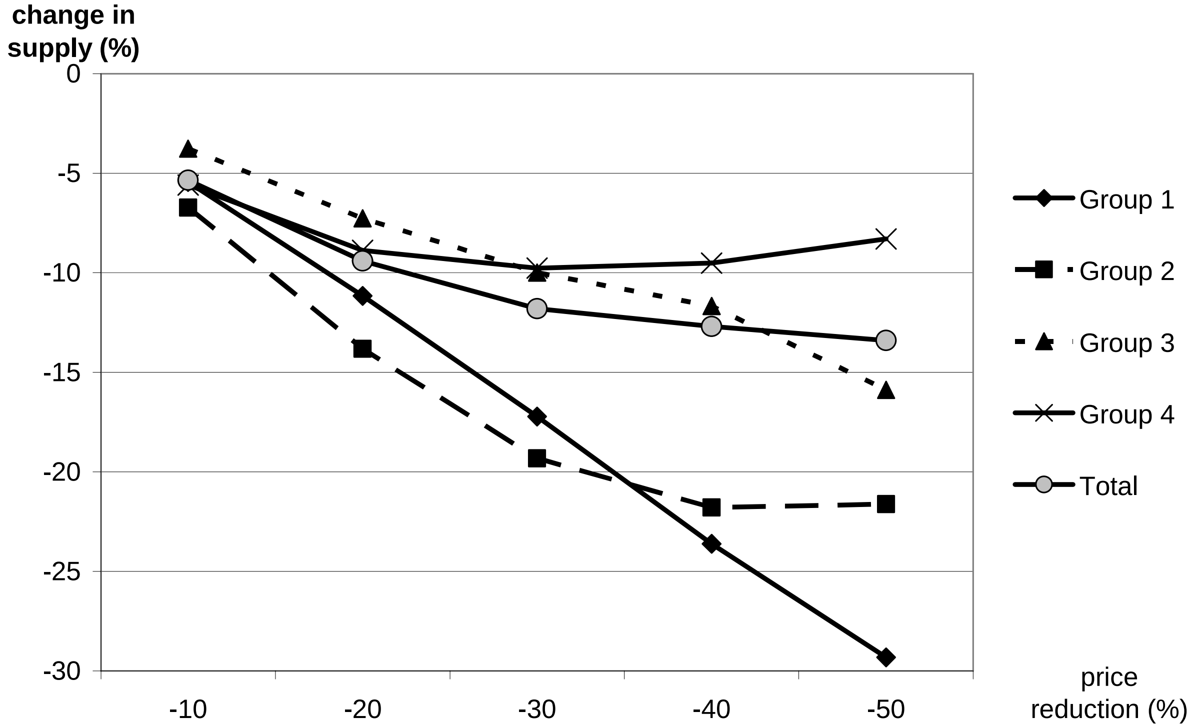

Figure 34. Effects of reductions in price on the supply of sugar beet of the 4 farm groups

Figure 35 and Figure 36 illustrate the impact of a sole quota reduction on the C sugar beet and the total sugar beet supply respectively of the different farm groups. For all farms a quota reduction induces an increase of the sugar beet quota rent. The effect of the quota rent increase on the C sugar beet is, however, different for the farm groups.

The supply of precautionary C sugar beet responds positively to the quota rent increase and negatively to the A sugar beet quota reduction. For most farms, the impact of the quota rent is larger than the quota reduction resulting in a raise of the precautionary C supply. For the farms in group 1, this effect increases until a quota reduction of 20%, but is reduced by quota cuts of more than 20%. The C sugar beet supply increase can not compensate completely the supply reduction of A sugar beet and, therefore, the total sugar beet supply declines.

At some farms with a high quota rent, the precautionary supply function is not binding anymore and the dual variable of the precautionary supply function, σ, becomes zero. This explains the high increase of C sugar beet supply of the farms in group 4.

These farms can supply C sugar beet profitably for two reasons. First, due to the reduction of total sugar beet supply, the marginal cost of sugar beet supply has decreased. Second, the land rent, represented by the dual of the land constraint, also decreases. This second element, leading to the profitable supply of C sugar beet supply, is probably overestimated in our simulation due to the limitations of the selected farm sample. If farms without sugar beet supply were include in the sample, the reduction in the land rent would be lower, because not all farms are affected by the reforms and more competition for land could be observed.

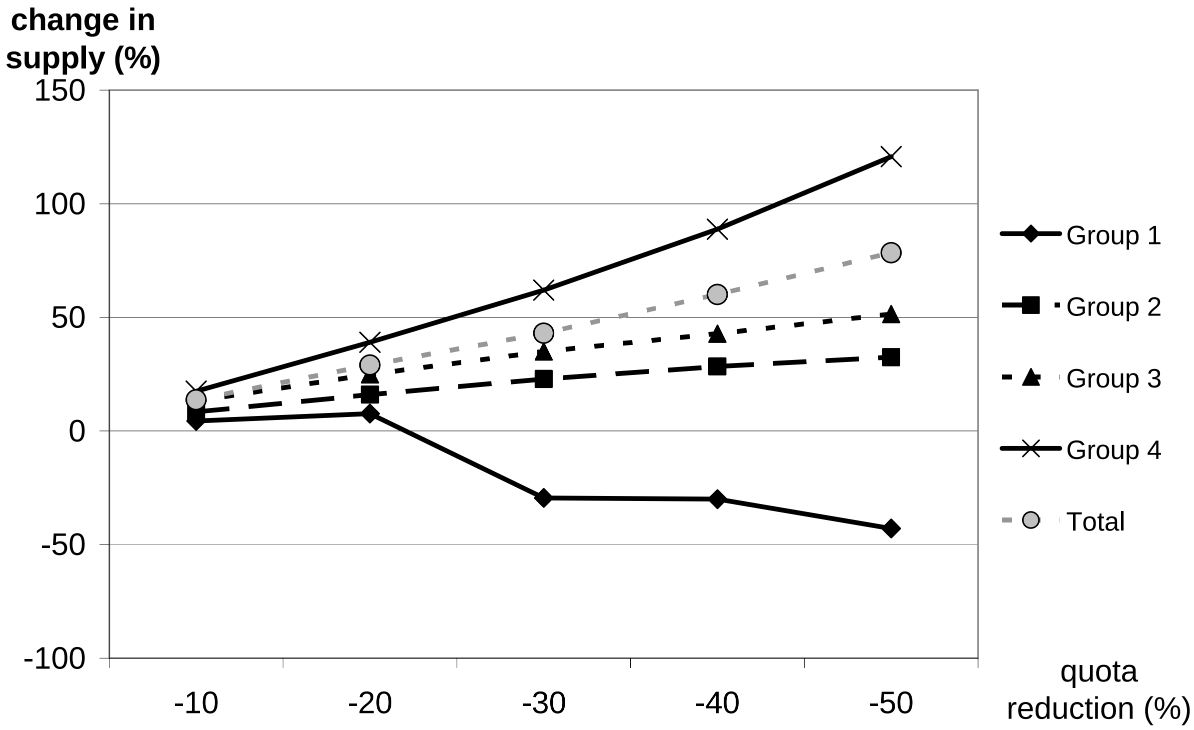

Figure 35. Effects of quota reductions on the supply of C sugar beet of the 4 farm groups

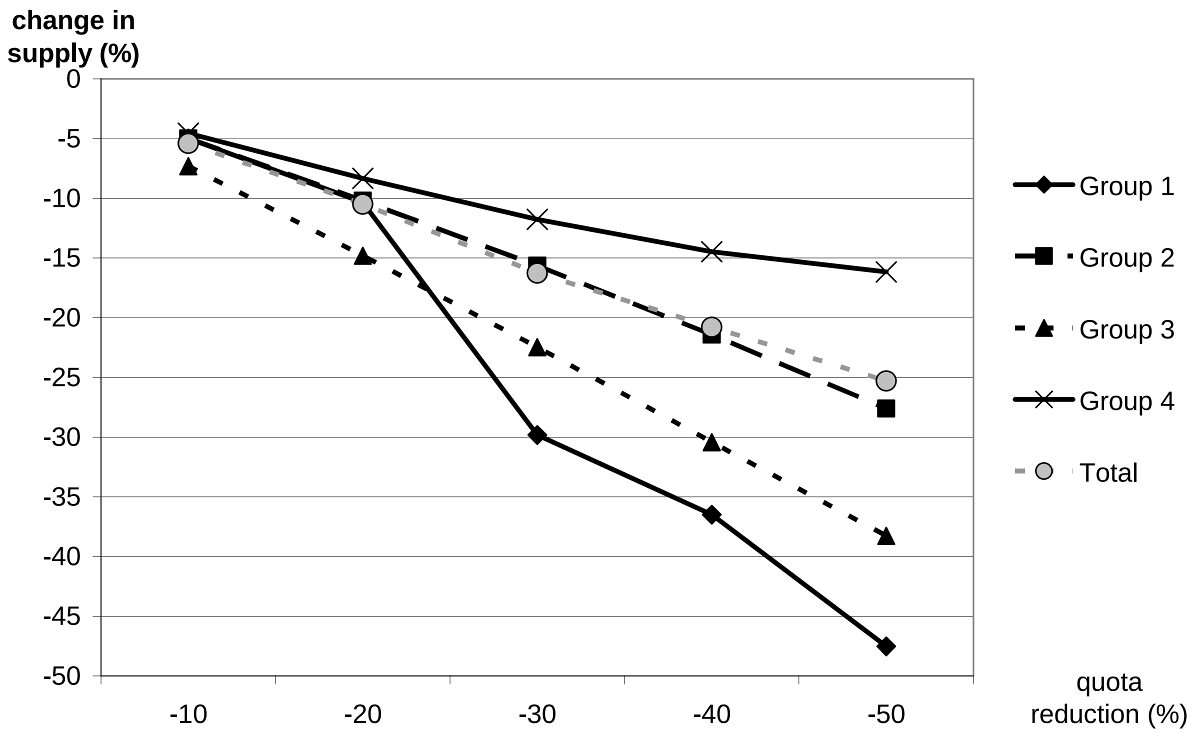

Figure 36. Effects of quota reductions on the supply of sugar beet of the 4 farm groups

5.3.3 Supply effects of a combined price reduction and quota reduction or increase

Figure 37 and Figure 38 show that the effects of a combined reduction in price and quota on sugar beet supply are much weaker than the sum of the separated effects of the reductions in price and quota. As observed in the results of group 3 in Figure 34, the impact of a price reduction is larger when the quota rent decreases and reaches zero. Because the quota rent increases when quota decreases, adding a combined price reduction to a quota reduction only slightly aggravates the impact on sugar beet supply.

There is a noteworthy difference in the results of group 2 and 3 between Figure 35 and Figure 37. In Figure 35 the impact of the quota reduction on the precautionary supply is compensated by a quota rent increase, resulting in an increase of precautionary supply. When the quota reduction is combined with a price reduction (Figure 37), the quota rent decreases, resulting in a reduction of the precautionary C sugar beet supply. For the farms in group 4 the reduction of precautionary supply is compensated by the increase of farms that are able to supply C sugar profitable.

Another remarkable result is the increase of total sugar beet supply of group 4 when the price and the quota reduce from 30% to 50%. This increase of sugar beet supply is driven by the commercial supply of C sugar beet that increases with a decreasing land rent. This means that the farms of group 4 would be able to acquire additional land from the other farms that decrease their sugar beet supply as a consequence of the price and quota cuts. As stated above, this result is not very realistic and is due to the fact that the sample only includes farms with sugar beet. In reality, more players are involved in the competition for land.

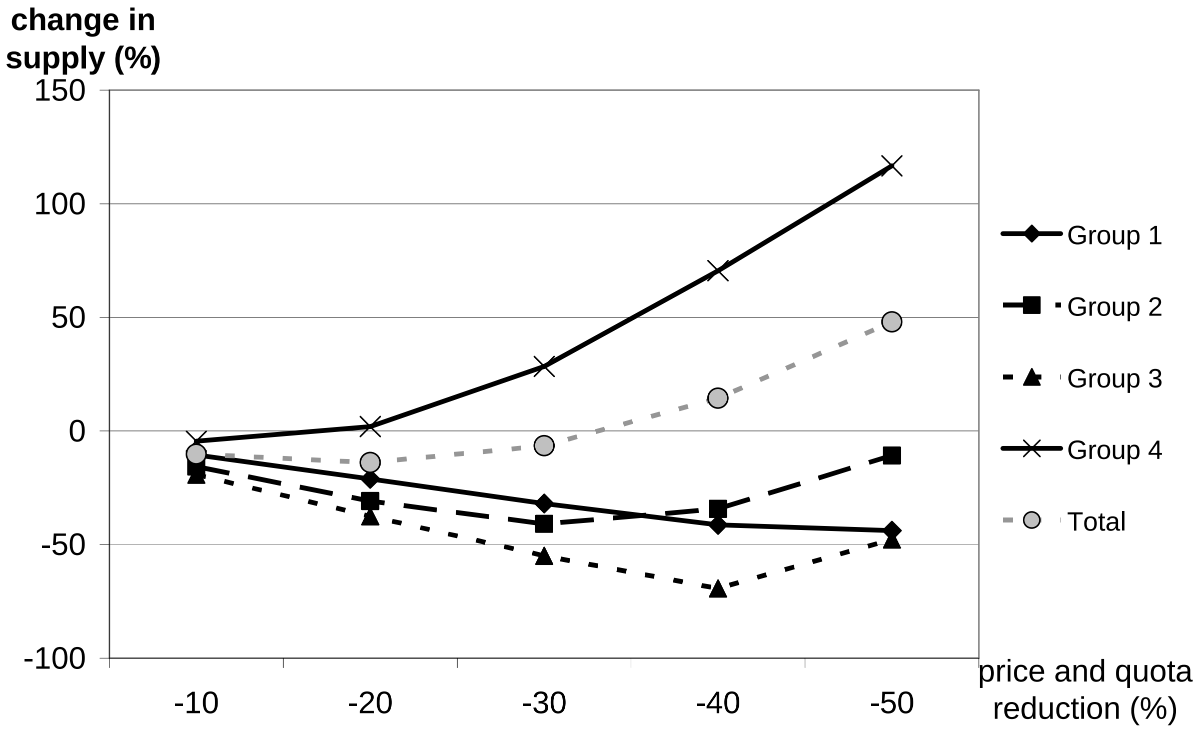

Figure 37. Effects of combined price and quota reductions on the supply of C sugar beet of the 4 farm groups

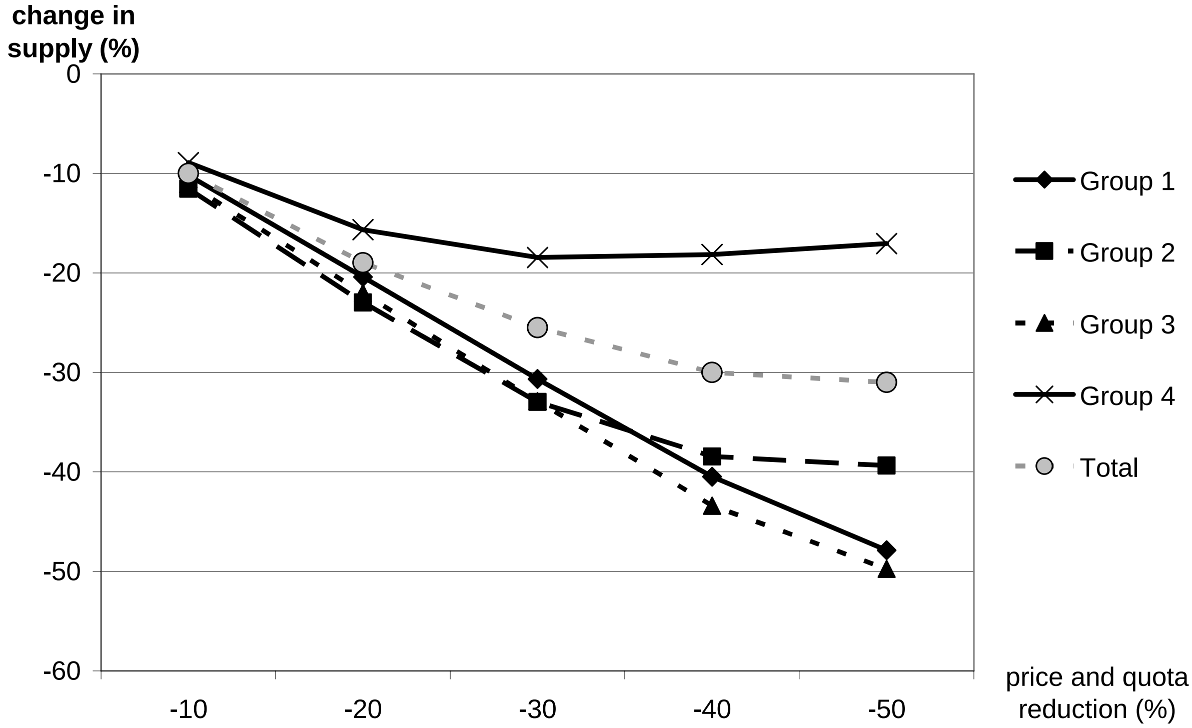

Figure 38. Effects of combined price and quota reductions on the supply of sugar beet of the 4 farm groups

Figure 39, Figure 40 and Figure 41 show the effects of an increase in sugar beet quota combined with a reduction of the A sugar beet price. This is what would happen if the Belgian sugar factories decide to buy additional quota.

Initially, the quotas are proportionally distributed over all farms. For a moderate price reduction and quota increase, all farm groups increase their total sugar beet supply. When the price of A sugar beet declines 30% or more, some farms do not fill their quota anymore and the quotas are redistributed to farms that still have a positive quota rent. Consequently, a quota increase of 30% combined with a price reduction of 30% or more leads to an increase of the supply of the farms from groups 2 and 4 while the supply of the farms of groups 1 and 3 starts to decline. For a quota increase of 50% combined with a price reduction of 50%, the quota rent approaches zero. From that moment on, not the whole available quota is supplied and total sugar beet supply starts to decline.

As a result of the increase in available quota, sugar beet suppliers shift their sugar beet production towards A sugar beets. The supply of precautionary C sugar beets declines as a consequence of the quota rent reduction for all farm groups.

An increase in quota combined with a reduction in the price induces an increase in total supply of sugar beets, but some farms decrease their total sugar beet supply. E.g., the increase of quota of the farms in group 1 does not compensate the decrease of precautionary supply, due to the high percentage of precautionary supply. To a lesser extent, this is also what happens at the farms of group 2. With a price reduction of 30% or more, there is, nevertheless, an increase in total sugar beet supply of group 2 for two reasons. First, the decline of precautionary supply is smaller for smaller quota rents, and, second, the quota transfers that occur for price reductions of 30% or more lead to an increase of sugar beet supply of group 2.

The increase of supply of quota sugar beet of the farms in group 3 is larger than the decrease of precautionary supply for moderate price reductions and quota increases. For price reductions of 30% or more the quota rent reaches zero at some farms of group 3 and, therefore, the total sugar beet supply starts to decline.

The supply of sugar beets of group 4 benefits from the price reductions and quota increases thanks to: i) increase of precautionary supply, ii) decrease of land rent and commercial supply of C sugar beet and ii) quota transfers from other farms.

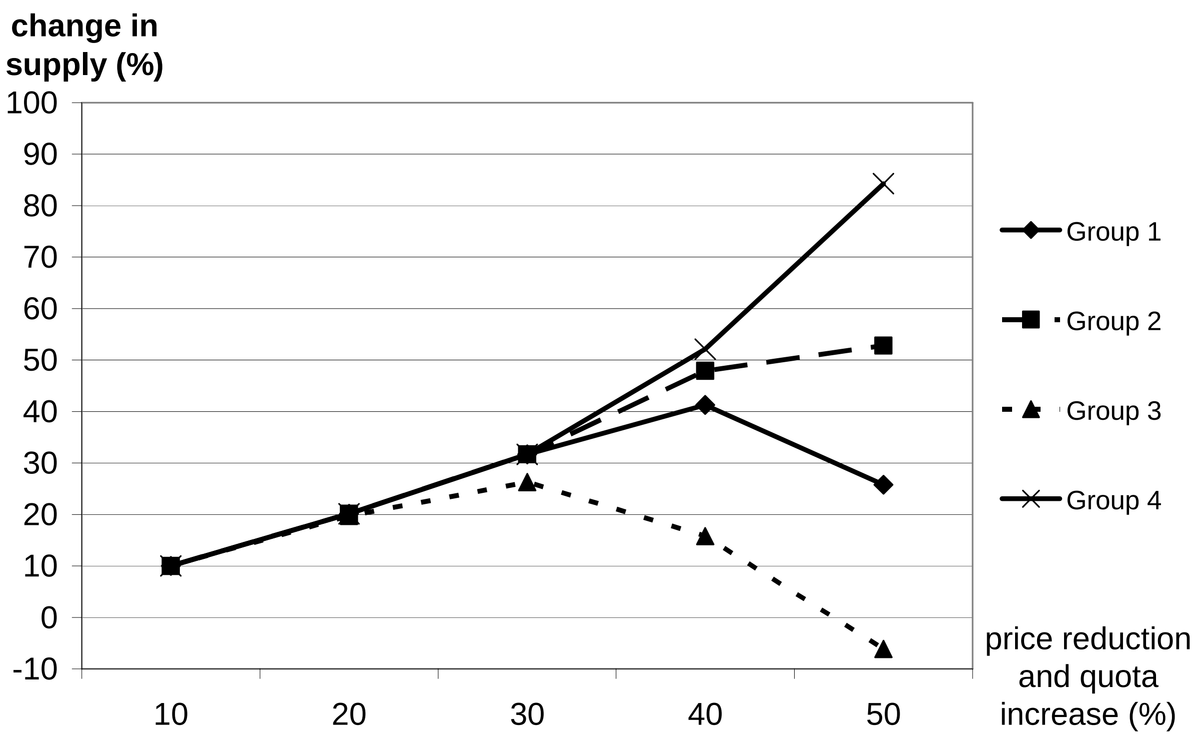

Figure 39. Effects of combined price reduction and quota increase on the supply of quota sugar beet of the 4 farm groups

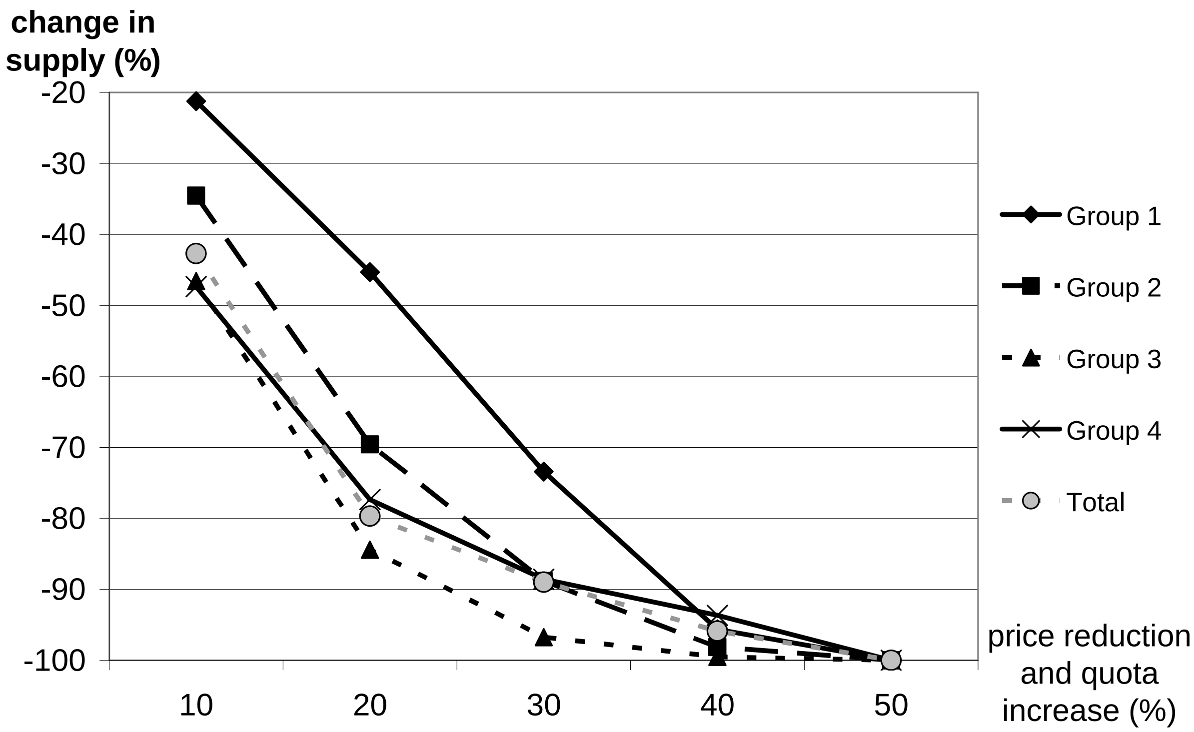

Figure 40. Effects of combined price reduction and quota increase on the supply of C sugar beet of the 4 farm groups

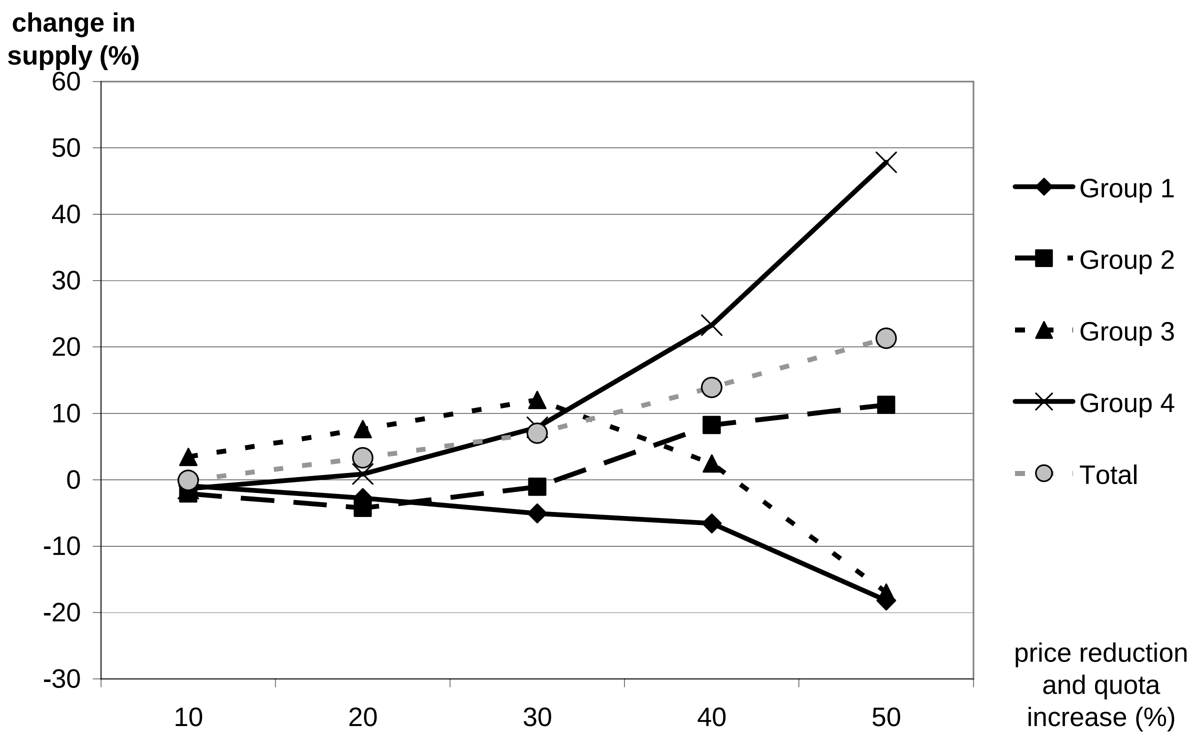

Figure 41. Effects of combined price reduction and quota increase on the supply of sugar beet of the 4 farm groups

5.3.4 Supply effects of compensation mechanisms

Figure 42 and Figure 43 indicate the supply effects of compensating the A sugar beet price reduction with coupled direct acreage subsidies in case of a 39,5% reduction in the A sugar beet price as agreed by the European council in November 2005. As expected, a coupled sugar beet subsidy mitigates the supply effect of the reduction in the price. The coupled compensation is affected by a modulation of 5%. This means that from the subsidies higher than 5000 euro, 5% is reduced. The larger farms, mostly situated in group 4, are most affected by the modulation for high compensation levels. Therefore, for 100% compensation, the largest decrease of supply of sugar beets is observed in group 4. The farms of groups 1 and 3 are almost not affected by modulation and, for that reason, 100% coupled compensation does not change their supply behaviour.

A small compensation level gives already a significant increase of sugar beet supply of farms in group 1, 2 and 3 for two reasons. First, the compensation increases the quota rent, which, in turn, increases the precautionary C sugar beet supply. Second, supply of quota sugar beet remains profitable at more farms, resulting in less quota reductions from quota transfers. For the farms of groups 4 the two effects work oppositely. The precautionary C sugar beet supply is increased, similar to the farms in other groups, by quota rent increases, but the farms can obtain fewer additional quota from quota transfers. Fewer quota transfers lead on the one hand to a lower increase of precautionary C supply but also to a lower supply within the quota. Therefore, the total sugar beet supply of group 4 even decreases with 20% compensation compared to no compensation.

There are no quota transfers anymore for higher compensation levels. The differences in supply behaviour between the groups are, therefore, only induced by differences in precautionary C sugar beet supply. Group 4 shows a larger reduction in the precautionary supply than other groups, because the farms of group 4 are more affected by modulation of the compensations.

The percentage of C sugar beet supply plays a role in the impact of compensation on the total sugar beet supply. Due to the higher percentage C sugar beet in groups 1 and 2, their total sugar beet supply reacts more to the coupled compensation than the supply of groups 3 and 4.

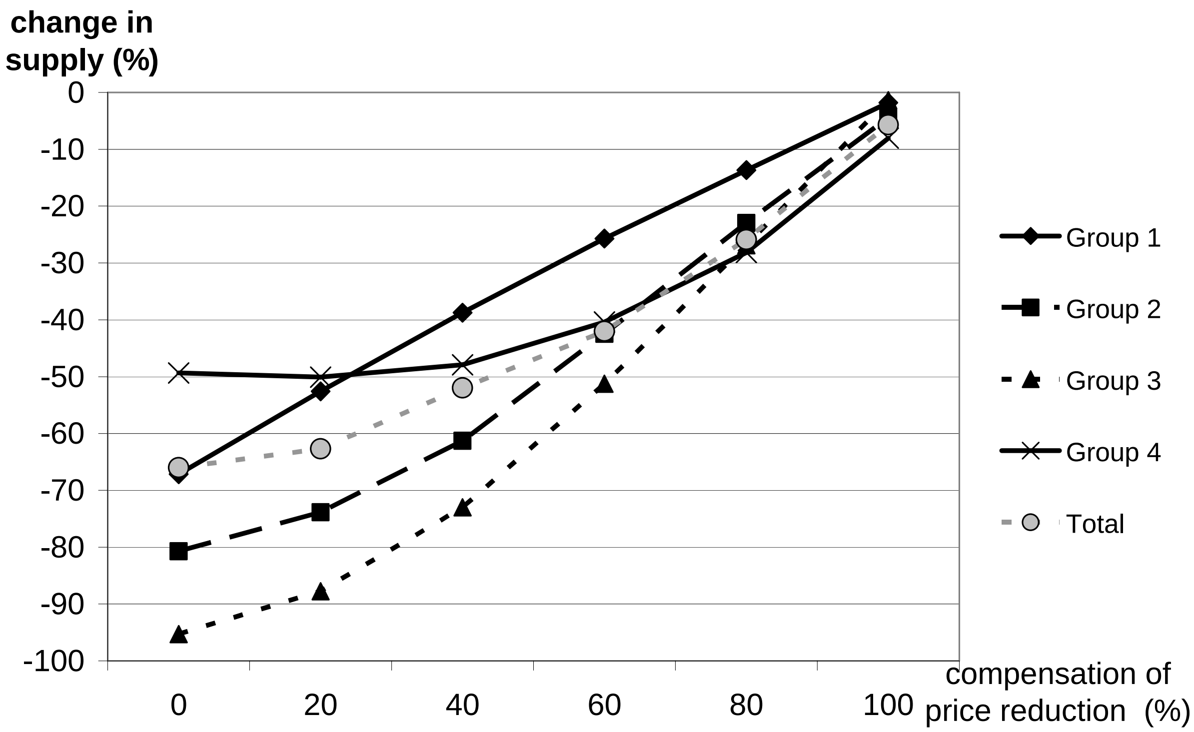

Figure 42. Effects of coupled compensation subsidies on the supply of C sugar beets for a 39,5% reduction in A sugar beet price

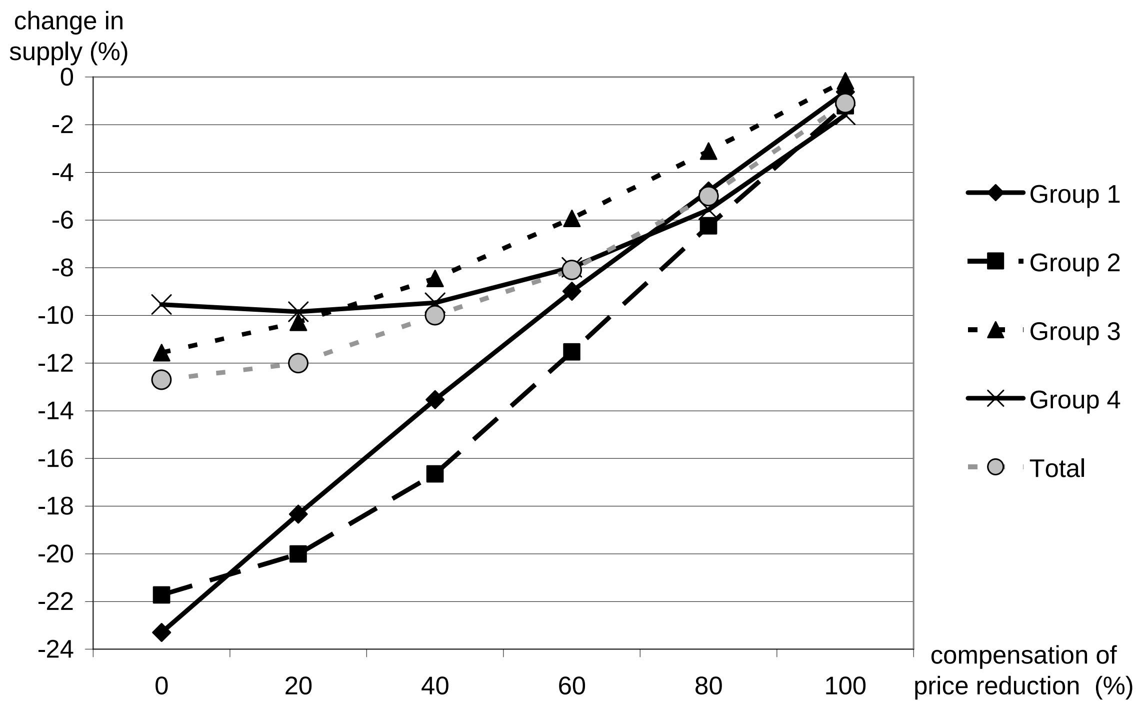

Figure 43. Effects of coupled compensation subsidies on the supply of sugar beets for a 39.5% reduction in A sugar beet price

In contrast to the coupled compensation, a decoupled sugar beet subsidy comes as an addition to the total decoupled subsidies that are granted to the farm according to its eligible area, i.e., all land not planted with potatoes and vegetables. The decoupled direct payments have in this sample of farms no supply inducing effect for sugar beet, because the eligible area is not the limiting factor for activating decoupled payments. This result corresponds exactly to the results of Chapter 4.

5.3.5 Income effects of price and quota reductions

As in Chapter 4, income effects are measured here as changes in total farm gross margins.

Figure 44 shows the effects of price, Figure 45 the effects of quota reductions and Figure 46 the impact of the combinations of both reductions on the total gross margins of the farm groups. Because sugar beet is currently an important and the most profitable activity among these sugar beet farms, the total gross margin is significantly affected. The aggregated total gross margin declines more sharply as a result of a reduction in price than quota.

The differences in changes in gross margin between farm groups is mainly driven by differences in quota rent and the share of quota sugar beet in the total crop plan. The farms in group 3 have the lowest quota rent and their gross margin is, therefore, least affected by the sugar beet price and quota cuts. Conversely, the farms in group 4 have a very high average quota rent (25 euro/tonne) and, as a consequence, the decline in the gross margin is higher than for the farms in group 3.

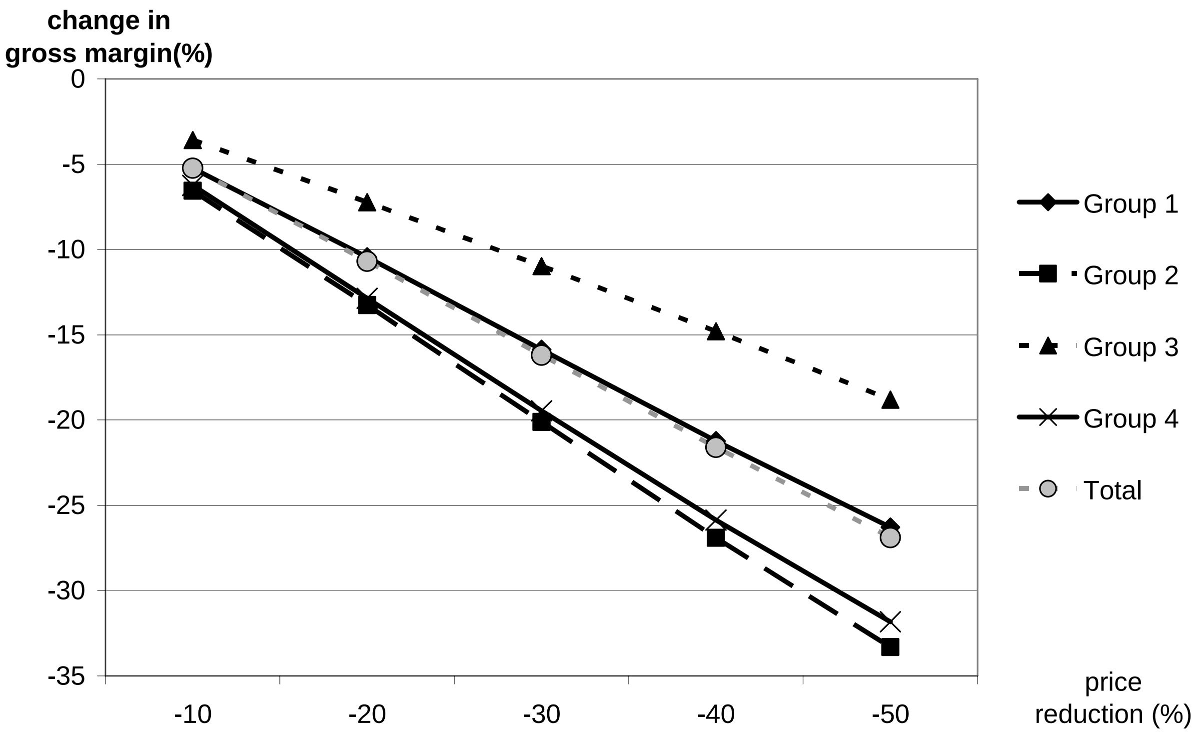

Figure 44. Effects of reductions in price on the gross margin of the 4 farm groups

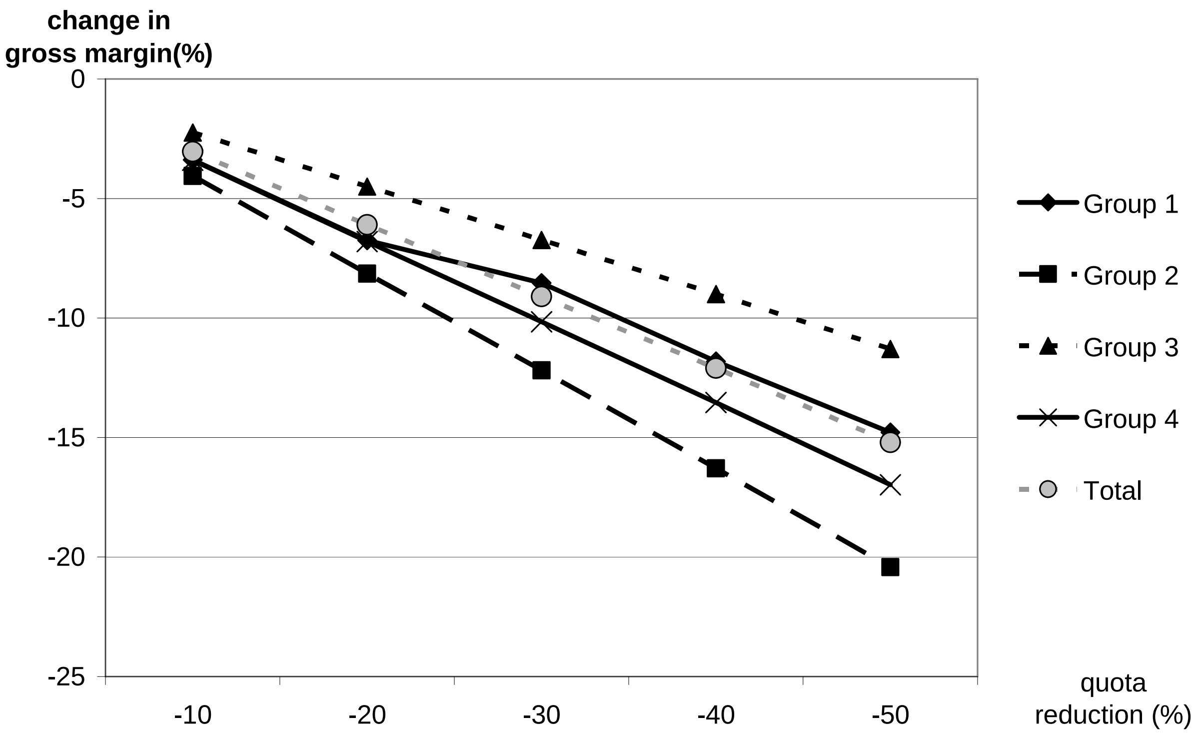

Figure 45. Effects of reductions in quota on the gross margin of the 4 farm groups

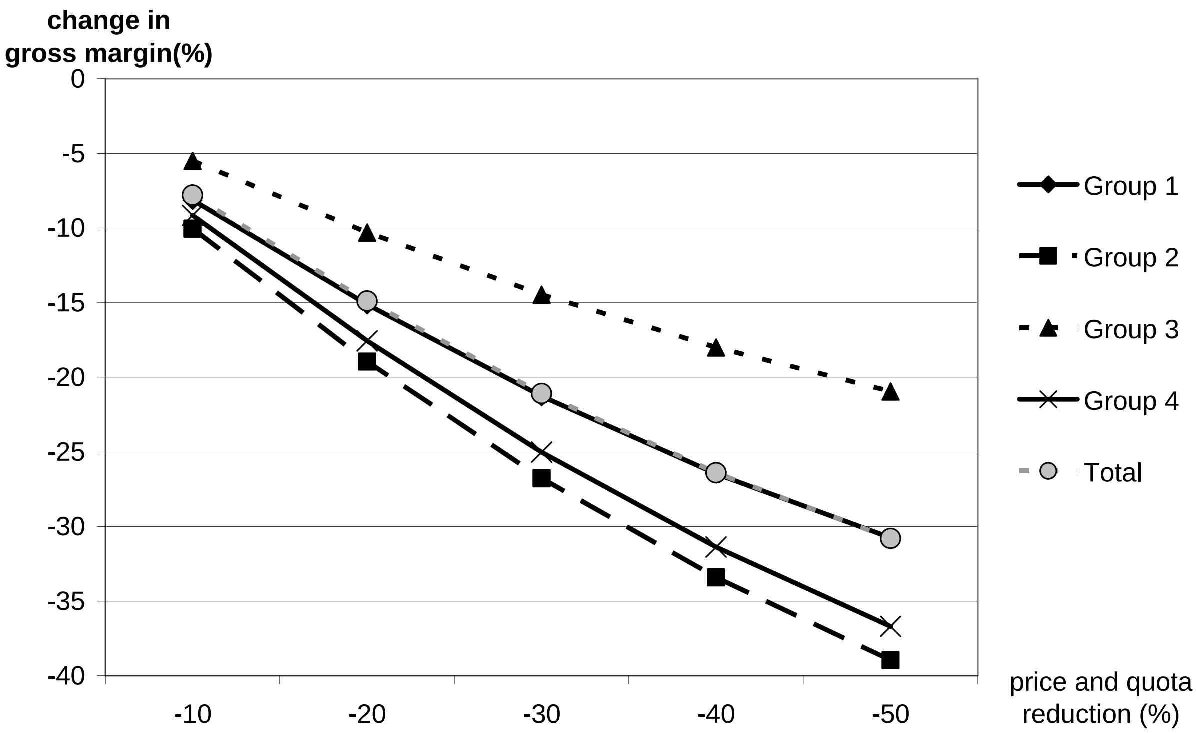

Figure 46. Effects of reductions in price and quota on the gross margin of the 4 farm groups

Figure 47 shows the effects on the gross margin of an increase in sugar beet quota combined with a reduction in the A sugar beet price.

For a moderate price reduction and quota increase, the results look similar to a sole price reduction. The gross margin decreases more at farms with a high quota rent than at farms with a lower quota rent.

Price reductions of A sugar beet of 30% or more induce transfers of quota, which provoke a reduction of the gross margin of farms that can not fill their quota anymore. Mostly farms of group 4 benefit from the quota transfers and, therefore, their loss of gross margin of a combined price reduction and quota increase is less severe than their loss of gross margin of a sole price reduction.

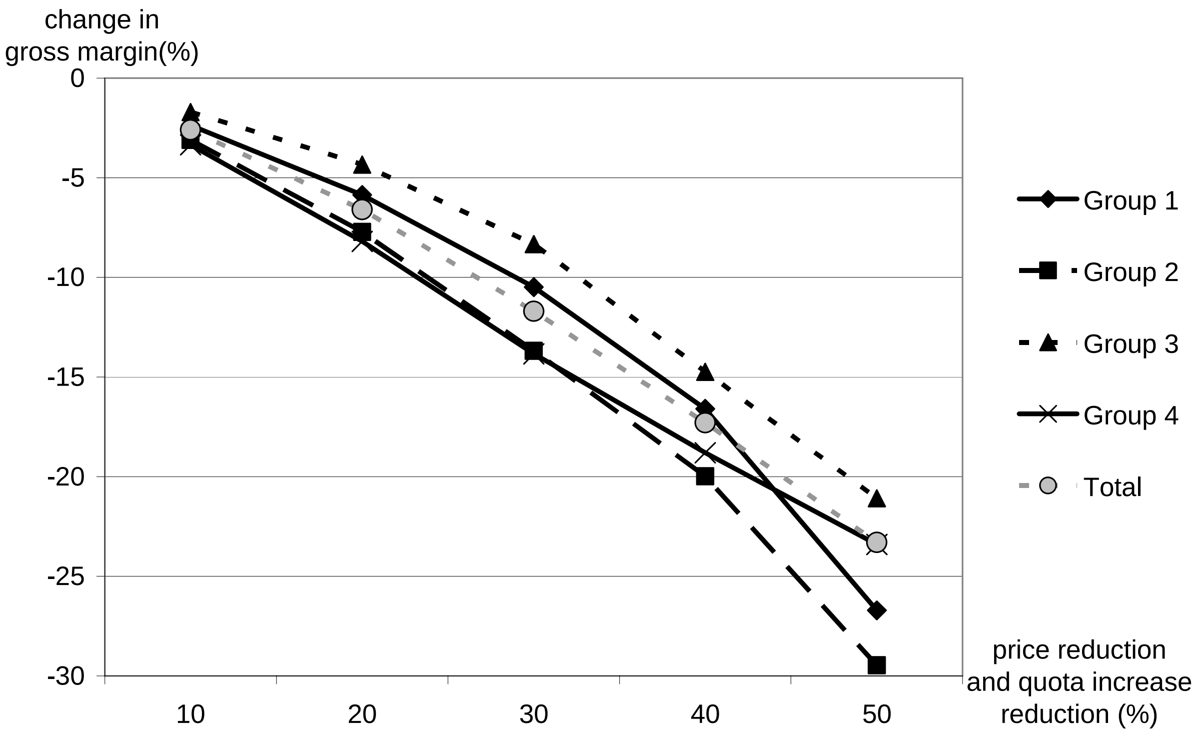

Figure 47. Effects of reductions in price and increase of quota on the gross margin of the 4 farm groups

Figure 48 and Figure 49 show the effects of compensating the A price reduction with coupled and, respectively, decoupled direct acreage subsidies on the aggregated gross margin of the simulated FADN sample for a 39,5% reduction in the price. Decoupling the compensation subsidies mitigates the decline in total gross margin because, for the same amount of subsidies, sugar beet farms have more flexibility in allocating their activities to maximise their total gross margins. The difference in gross margin between coupled and decoupled subsidies is, however, very small. The simulation of the sugar CMO reform, as decided in November 2005, in our model induces a decline of about 6% in aggregated total gross margin.

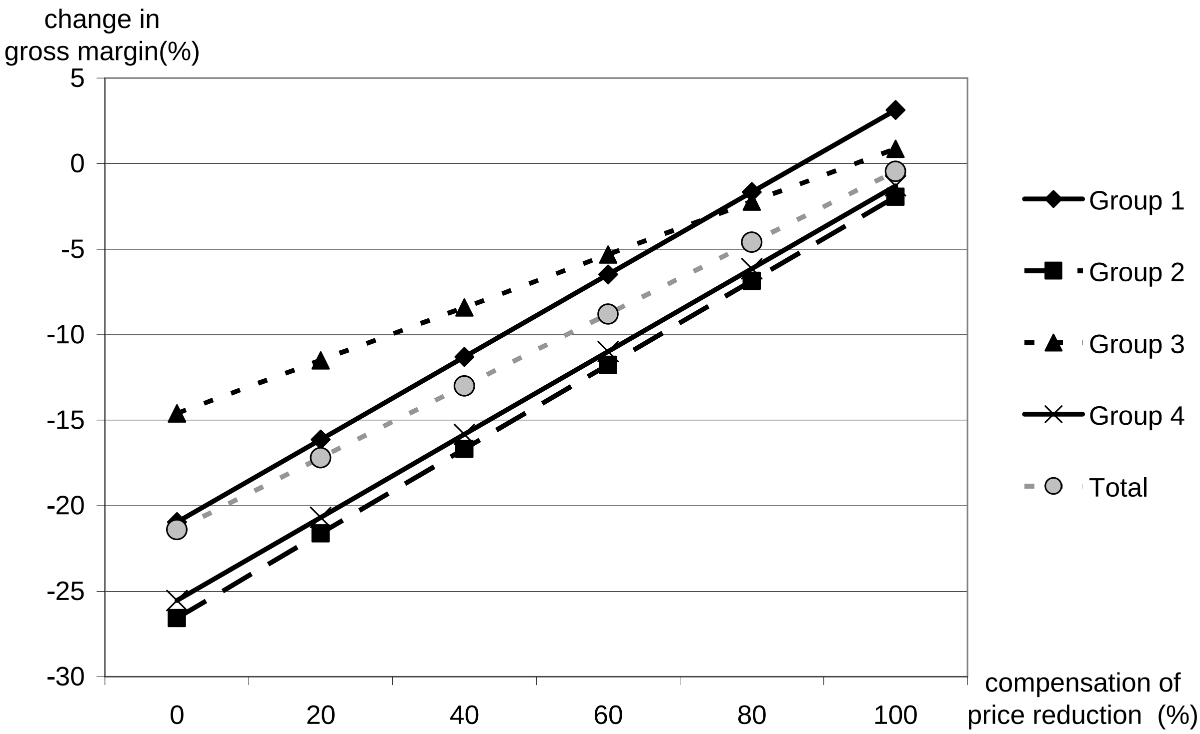

Figure 48. Effects of decoupled price reduction compensation subsidies on gross margin of the farm groups for a 39,5% reduction in price.

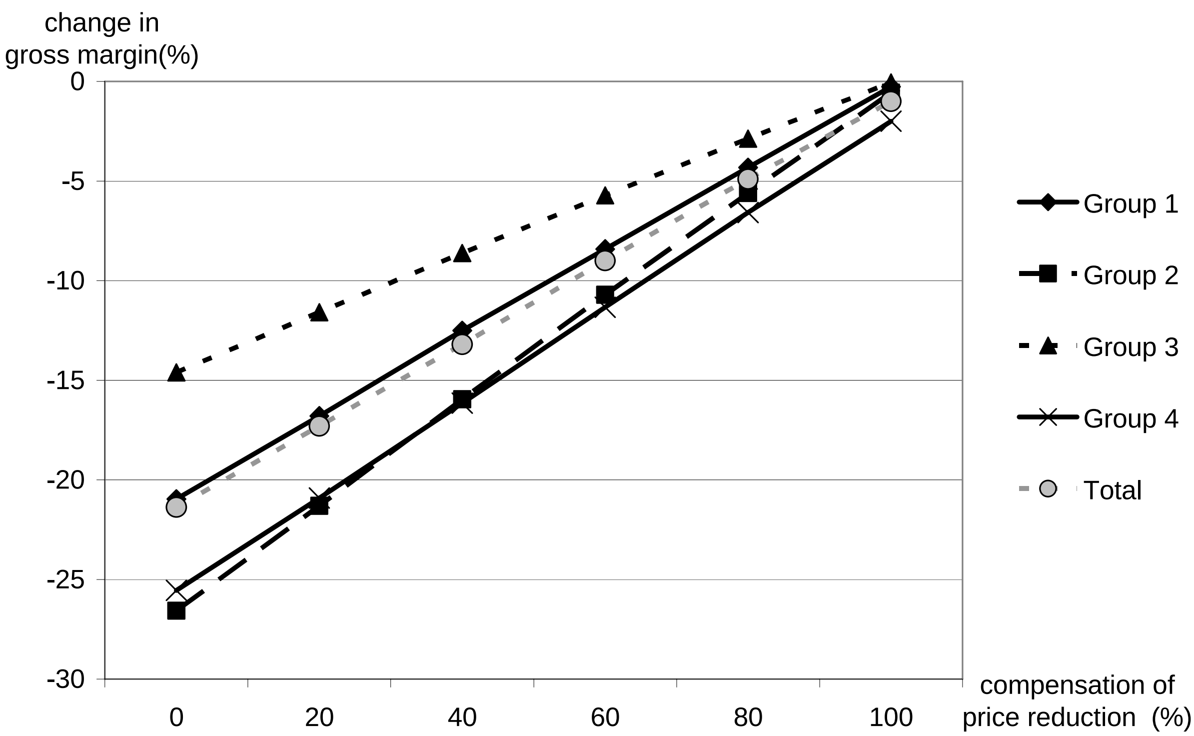

Figure 49. Effects of coupled price reduction compensation subsidies on gross margin of the farm groups for a 39,5% reduction in price.

5.3.6 Supply effects on other crops

Table 22 shows to what extent a price reduction compensation, whether coupled or not, affects the supply of the other major crops of the sugar beet farms in case of a 39,5% reduction in the price and a 64,2% compensation of the price reduction. Analogous as in Chapter 4, a price reduction compensation coupled to sugar beet acreage has no additional influence on the supply of the other crops. In contrast, a price reduction compensation decoupled of sugar beet acreage increases the supply of the other crops, i.e., mainly cereals, maize and fallow.

Table 22. Effects of a price reduction compensation of 64,2% on the supply of selected crops of sugar beet farms within the Belgian FADN for a 39,5% reduction in A sugar beet price

	Difference (%)									
	Coupled compensation					No compensation / Decoupled compensation				
	Group 1	Group 2	Group 3	Group 4	Total	Group 1	Group 2	Group 3	Group 4	Total
Total sugar beet	-8,1	-10,4	-5,4	-7,5	-7,4	-23,3	-21,7	-11,6	-9,5	-12,7
A sugar beet	0,0	0,0	0,0	0,0	0,0	0,3	0,3	-0,6	0,3	0,0
C sugar beet	-23,1	-38,3	-46,3	-38,0	-38,7	-67,2	-80,7	-95,3	-49,4	-66,0
Winter cereals	2,8	3,3	3,7	3,3	3,4	6,6	7,7	8,5	7,7	7,9
Summer cereals	0,0	3,0	4,0	3,2	3,4	0,0	7,1	9,2	8,2	8,1
Maize	7,2	0,0	1,7	3,3	2,8	16,8	0,0	4,0	7,6	6,5
Wet pulses	0,0	0,0	1,9	1,3	1,4	0,0	0,0	4,5	3,0	3,4
Potatoes	0,6	1,8	0,6	1,3	0,9	1,5	4,2	1,5	3,1	2,2
Chicory	0,0	-1,0	-1,9	-3,4	-2,9	-29,8	-35,5	-27,5	-26,7	-27,9
Industrial crops	1,5	0,0	0,7	0,0	0,7	3,6	0,0	1,7	0,0	1,7
Other arable crops	0,0	4,5	0,5	0,8	0,7	0,0	10,4	1,1	1,8	1,6
Fallow	0,1	0,1	0,5	3,8	2,1	-0,1	0,0	2,0	9,6	5,3

The results of Table 22 are probably not representative for the total supply of other crops in Belgium because the sample only consists of farms producing sugar beet. In Belgium cereals, maize, pulses, potatoes and other crops are also produced at farms without sugar beet, which are not represented here.

5.4 Conclusions

5.4.1 Conclusions with respect to the application

Due to the similarities between the EMP and PMP sugar module, the conclusions for the PMP version that are described in 4.6.1 are also valid here. There are, however, also some differences in the aggregated results.

The aggregated results are more responsive for the EMP than for the PMP sugar beet module, due to the flatter estimated cost function and the resulting higher quota rents with the EMP application. The fact that in the EMP results some farms, for scenarios where the quota rents increase, become profitable C sugar beet suppliers creates the largest difference with the PMP results. However, when the sample would be completed with all non-sugar beet farms, there would be more competition for land and higher land rents. Therefore, profitable C sugar beet suppliers would than not have been observed.

Chapter 5 provides more details on the differences between farms. This underlines once more the value of a farm-level approach because the policy makers are not only interested in the aggregated outcome, but also in the differences for different groups. The details on farm-level differences give also more insight in the driving factors of the aggregated outcome.

5.4.2 Modelling lessons

Chapter 5 resolves two of the problems of the sugar module of SEPALE presented in Chapter 4. Chapter 5 introduces a simultaneous calibration of all sugar beet specific parameters to avoid the ad hoc assumptions related to the quota rent. At the same time, the number of parameters in the precautionary supply function is increased resulting in a more flexible function that should be able to represent the precautionary supply behaviour more realistically.

As a result, the sugar module of SEPALE can be viewed upon as a real-world example of the general methodology proposed by Heckelei and Wolff (2003) that we have called EMP in this dissertation. The differences between the results of the PMP and the EMP approach are rather small. This confirms partially the sensitivity analysis of the PMP approach. Next subsection describes these differences, their cause and their consequences. The subsection thereafter tries to anticipate on the applicability of EMP in other situations.

5.4.2.1 Comparison of results of the PMP and EMP sugar beet module of SEPALE

The differences between the results at farm-level are mainly driven by the calibration approach applied to the sugar module. In the PMP version of the sugar beet module, the sugar beet parameters depend on the percentage C sugar beet supply, the average costs for sugar beet, the land price and the calibrated elasticities of other crops. In the EMP version the parameters are determined by differences in percentage C sugar beet supply, the average costs for sugar beet and land prices, but during calibration not by different supply elasticities of other crops. We think, therefore, that the farm-level results of EMP are more reliable, because the elasticities of other crops are only calibrated in a simplified way and probably prone to some bias. This bias can influence the PMP results, but not those of EMP.

Another difference between the PMP and the EMP approach is the use of the base data. The PMP model starts from the percentage C supply from one calibration year, while the percentage C supply in the EMP version comes from the estimation, which is based on several years.

5.4.2.2 Applicability of EMP

The results have shown that it is possible to apply EMP to real world situations. There are, however, some pitfalls that could be avoided here, but that could hamper future applications in other situations.

Complementary slackness conditions in estimation equations

Section 3.6.2.3 explains the problem, which is also reported by other authors (Gocht, 2005; Heckelei and Britz, 2005), of complementary slackness equation in an NLP model formulation.

In the current EMP sugar module of SEPALE, the problem is avoided by making assumptions on which constraints are binding and which not. However, in certain cases, when the duals of constraints are close to zero, the modeller is bound by insufficient information to make such assumptions. In order to increase the applicability of EMP, more research should be done on the topic of solving MPEC problems.

Estimation problems

The structure of an EMP model typically includes also all difficulties that could be encountered during an estimation process. Because an MP model is not built as the standard econometric problem with dependent and independent variable, in a lot of cases one can expect to have a model structure with endogeneity. The complementary slackness constraints are also in most cases non-linear in parameters and, dependent on the model, the estimator should also take care of limited dependent variables. Unless the model is simplified, the modeller may have to program an estimator himself, because standard econometric packages do not include an estimator that can deal straightforwardly with all these issues in one time.

Complexity of the model

Even though the application of the sugar module has been successful, the rest of the model still relies on a simplified model that is PMP calibrated. The simultaneous estimation of a farm-based sector model that includes the sugar module, supply behaviour of other crops and a module for the animal sector would be much more complicated. If the estimation of such a model is done step by step, the model has to rely nevertheless on assumptions on the interaction between the different modules.

This problem is also apparent in the estimation of the sugar module. The results of the estimation of the sugar parameters depend on the assumption that the approximation of the shadow cost of land, the land rent, represents the interaction between sugar beet and the other crops. All other forms of interactions are ignored.

General discussion and conclusion[20]

The dissertation demonstrates how different types (NMP, PMP and EMP) of mathematical programming models can be applied for farm-level policy analysis. The conclusion discusses the classification and the definition of the model types followed by a summarising overview of the applications of the three model types. Next, the conclusion gives some indications of model type selection. The dissertation finalises with some general concluding remarks and recommendations for future research.

Definition and classification of the 3 model types

NMP is defined as the type of models in which no algorithm is used or specific steps have been taken to adjust the model parameters to guarantee that the model precisely reproduces the observed data. Differently stated, NMP models are MP models without calibration.

According to the definition used in this dissertation, both PMP and EMP rely on calibration. The difference between both may not always be very clear, because there is still a lot of discussion on the meaning of calibration and estimation, certainly within the literature of real-business-cycle economics. Besides the difference in opinion on the meaning of the words, there is also acrimony on the correctness and utility of different approaches: model calibration versus model estimation (Quah, 2005). Contemporary economic analysis includes two broad traditions of fitting models to data. Estimation uses stochastic, theory-based, reduced form models with few parameters, while calibration of models is done by an extensive collection, and computation, of consistent fitted values. Although it is widely recognized that both calibration as estimation fit a model to data and that the exercises are similar, Balistreri and Hillberry (2005) indicates that the focus of both types of research is different: the calibrators concentrate on counterfactual simulation while the focus of estimators is on hypothesis testing.

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[20] Parts of the general discussion and conclusion have been published as:

Buysse, J., Van Huylenbroeck, G. and Lauwers, L. (2006). Normative, positive and econometric mathematical programming as tools for incorporation of multifunctionality in agricultural policy modelling. Agriculture, Ecosystems & Environment, in press.

The definition of distinction between PMP and EMP used in this dissertation is as follows. Both PMP and EMP are useful methodologies for calibration of a cost function at farm level starting from positive information but, the calibration of PMP is deterministic, while the calibration of EMP is stochastic. This means that there are zero degrees of freedom in the PMP calibration equations while there are non-zero degrees of freedom in the EMP calibration equations. To obtain zero degrees of freedom, the PMP model has either a simple functional form or it is fed with casual empiricism or knowledge from separate econometric studies (the definition of calibration according to Hoover, 1995). The EMP calibration with non-zero degrees of freedom relies on some econometric minimisation algorithm to adjust the parameters of the model such that the simulated output deviates minimally from the real output (the definition of calibration according to Kleijnen, 1993).

The classification that we have made between the three types is thus not based on the amount of econometrics involved in the model. E.g., the NMP application in this dissertation relies on more estimated functions than the PMP and EMP applications. The classification rather refers to the way the final step is taken of bringing different model pieces together. We are aware that the presented typology does not completely correspond to other classifications and that discussion on the classification could be possible. E.g., Heckelei and Britz (2005) define the use of phase 1 of a defining character of PMP and call the newly developed approaches 'alternative approaches to calibration and estimation or programming models'. According to that definition SEPALE is not a PMP method but belongs to the alternatives, while Paris and Howitt (1998) is an application of PMP. Howitt (2005) distinguishes PMP (zero degrees of freedom) and ill-posed ME models (negative degrees of freedom) of which Paris and Howitt (1998) is an example. The place of the SEPALE applications is not very clear in Howitt's classification. The classification in itself is, however, not important. The classification only facilitates the overview of model types and can support the selection of a model for a specific research task. More important than the classification, the differences and similarities between different modelling approaches should become clear.

Therefore, a detailed comparison as well as applications of each model type has been presented. Each application provides us with some experiences with respect to the model type and can lead to policy recommendations. The policy recommendations of the individual applications can be interesting, but are not subject of this general conclusion. Instead, the general conclusion and discussion presents an overview of the strengths and weaknesses of the three model types. This overview and the experience can be used as hints on model type selection for future research.

Summarising overview of the applications of the three model types

NMP has been applied for the development of a dairy farm model. The model has shown its utility for the assessment of the impact of management decisions on the nutrient balance of a dairy farm. The strength of NMP is this case is the possibility to integrate separately known functions in one simulation model in order to draw conclusions not only at field or at cow level, but also at overall farm level. As illustrated, the model can be used to evaluate either management options at farm level, but also the effect of possible policy options.

The dairy farm application has also illustrated one of the main drawbacks of NMP: the models' inability to simulate baseline conditions. The problem of validating this type of models is to our opinion mainly due to problems of data gathering and influence of external parameters on the data. This shows at the same time an important advantage of the model: external parameters influencing observed nutrient balances such as weather conditions and measurements errors can be eliminated, so that the exact influence of practices and systems can be evaluated. Or put in a phrase by Hazell and Norton, 1986: "It is after all better to use good logic (embodied in the model) for policy analysis than to compound the problem of poor data with poor logic."

Nevertheless, modellers have devoted more and more time to calibration to avoid the critique of simulation problems with baseline conditions. This has lead to the development and formal description of PMP, which has renewed the interest in MP. The main strength of PMP is the possibility to make use of very few data to model agricultural policies, while being able to generate plausible results. The plausibility of the results is inherited from the possibility of the introduction of real-world constraints and of the calibration step.

PMP is illustrated in this dissertation with SEPALE. SEPALE consists of a collection of farm-level PMP models, of which the parameters of the individual farms are calibrated based on the FADN data. SEPALE is, therefore, an illustration of how PMP can be used with large farm-level samples. This model makes it possible to account for the individual farm structure and the interaction between farms. The possibility to simulate the effects according to farm size or other criteria such as region or farm type also allows to model structural changes of the sector. SEPALE has been used to simulate the June 2003 CAP reform with varying decoupling rates and modulation levels and thresholds.

A significant part of the dissertation is devoted to the modelling of quota, the sugar CMO in particular. The sugar regime forms an interesting challenge for modellers because three important issues have to be tackled: C sugar beet supply, quota rent approximation and quota transfers. The most complex element, for sugar beet, is the problem of out-of-quota supply. Therefore, a precautionary supply function is introduced in the model. The precautionary supply function describes the increasing C sugar beet supply as a result of increasing quota or quota rent. In order to make the link with the quota rent during simulation, the programme is rewritten in its complementary slackness conditions.

The sugar beet application has illustrated the strengths of PMP of generating plausible results with a rather simply model. However, it has, at the same time, exposed its weaknesses because calibration of the sugar module and the quota rent approximation have only been possible with simplifying assumptions. It is certainly true that the plausible results generated by a PMP model do not guarantee that the response is correct. The limited functional form of the model and the ad hoc calibration assumptions may influence the results for a great deal and can introduce subjectivity in the analysis.

To mitigate these problems, time has been invested in the development of an EMP version of the sugar module. The EMP application has removed the theoretical objections to the ad hoc calibration assumptions and has also made a more flexible functional form for the precautionary supply function possible. Nevertheless, the GME estimation is still dependent on the choice of support points and the choice which parameters should be common for the sample. These choices can be subject to discussion. In a way, one can, therefore, argue that EMP does not remove the problems of subjectivity. It is only rearranged into a different configuration. The main results and conclusions of the EMP and PMP sugar module are also quite similar. The most important difference is that the quota rent of the EMP application is a bit higher and the cost functions flatter.

A more interesting aspect of the results of the EMP application is the presentation of the reactions of the different farm groups. Once more, these results highlight the utility of the farm-level approach. The farm-level approach not only makes it possible to segregate the results according to farm characteristics. It is also a good instrument to illustrate the economic mechanisms behind aggregated results and it can simulate structural changes. It should, however, be emphasized that the farm-level aspect is not limited to EMP. Also NMP and PMP model can operate at farm-level.

The applications have illustrated the strengths and weaknesses of the MP modelling approaches. The question is then how to select a model type for a certain research task.

Model type selection

The choice of method depends on three elements: data availability, model focus and research scope.

Data availability depends on the resources for data collection but also on the type of policy instruments to model. For a new policy, radically different from the previous, less data are available and therefore more normative techniques have to be used. Data availability remains a major prerequisite for applying PMP and EMP. When no empirical data are available, an MP model will inevitably rely on an NMP technique. In EMP, the combination of econometrics and programming may help to take full use of the scarce available data.

The model focus can be prescriptive, explorative or descriptive. A model intended for prescription can only rely on NMP. In a certain sense, the technique can "describe" what would happen to a reference population when the actors follow the prescribed recommendations. NMP can also be very useful for demonstration of sensitivity and for gaining insight in a problem. Therefore, NMP is suited for explorative research of new opportunities and innovations within a context of resource constraints. PMP and EMP on the contrary, will be preferred for description and prediction of behaviour and reactions on modifications in existing policy instruments. These tools are indeed able to take into account real-observed behaviour (and not a theoretical full adoption of prescriptive recommendations) and will therefore result in more reliable prediction of consequences of changes in policy parameters. However, this does not means that PMP and EMP would not allow for incorporating new policy measures or innovations. These approaches are positive for those elements that can be integrated in the calibration, but, due to the MP side of the approach, PMP and EMP can also be normative for those parts where only some basic information about the system (e.g. coming from experimental stations) is available. The main risks for simulation biases arise, however, when the external introduced normative information drastically intervenes with the positively calibrated parameters reflecting the unobserved constraints.

Generally, EMP could be preferred to PMP because, due to the advanced techniques of descriptive analysis of econometrics, the technique is supposed to be more robust and better at describing past behaviour. However, the development of an EMP model probably requires more resources for data collection and for solving the problem numerically.

Finally, the research scope also influences the choice of model. A model only developed for a specific case can probably attract fewer funds. Therefore, the preferred technique will likely depend on the time needed for development. In a more general decision support system, with the possibility of a more or less continuous funding and knowledge exchange organisation, applicability and robustness will become major criteria for model choice.

The applications in this dissertation have also illustrated the influence of the available time on the choice of method. When the discussion on the Sugar CMO reform has started, stakeholders were interested in a quick analysis of the reform proposals, which was first based on a rather simple PMP model. Later, the PMP variant of the sugar module has been refined and finally turned into an EMP model. Also the application of SEPALE to simulate the MTR has shown the influence of the model scope. The transfer of direct payment entitlements was only a secondary research question and not enough time is yet invested to solve the issue. In a future research project, where transferring of rights between farms is the focus, specific algorithms can be development.

Some concluding remarks and recommendations for further research

The dissertation gives a broad overview of the development of MP models and how to select a model type for a specific research task. However, the overview and the applications do not deal necessarily with every aspect of the development and simulation.

One of the topics that has not been discussed is the sample selection. The PMP and EMP applications show nevertheless that the sample selection may influence the results significantly. Arfini *et al.* (2003) states that the biggest problem common to all the models solely based on the FADN sample is their representativity with respect to the regional universe, and the fact that this is strictly linked to the representativity of the FADN sample. The latter should be guaranteed at regional level for each farm type, but is obviously reduced when a further subdivision of the farms is made, such as for example, size class. Certainly when the model uses only a sub-sample of the FADN sample, results may not reflect reality. To solve the issue of representativity, Arfini *et al.* (2003) combine the FADN database with the land use database. This type combination of different databases is interesting aspect for further research, because it can improve the representativity and increase the availability of data.

Another issue that deserves more attention in further research is the validation of calibrated models. One of the important problems with validation of the economic models presented in this dissertation is the lack of good validation data because the recent CAP reforms with decoupled payments and strong price reductions of the sugar beet reform are not observed before. Kleijnen (1999) argues, nevertheless, that validation is possible even if no data are available. Even if real data are missing, there is still the possibility to do a sensitivity analysis and to use expert knowledge. If the simulation model's input/output (I/O) behaviour violates this qualitative knowledge, the model must be seriously questioned.

Even though this dissertation strongly advocates a farm-level MP modelling approach, many other valuable approaches exist, with which the described models can be enriched or coupled. With this respect, current efforts to enrich the model tools with GIS (geo-information systems), MAS (multi-agents systems), game theoretic heuristics (see e.g. Balman, 1997; Happe *et al.*, 2004) or with uncertainty in output prices and farmer's risk aversion (Havlik *et al.*, 2005) are promising. Another interesting contribution can be expected from institutional approaches, not only because institutions are part of the system that has to modelled, but also necessary to improve the policy support organisation. Own experiences strengthen our belief that human resources prevail on the mere mechanics of modelling. The model tool is not a jukebox, but needs corporate and evolving knowledge about systems. As a consequence, for an appropriate organisation of policy impact analysis, it is important to invest in modellers and not only in models.

Finally, another promising research area is the use of models to detect the appropriate objects for policy impact analysis: what will be the new prototypes of farming systems that may form the pillars of sustainable agriculture. According to Rossing *et al.* (1997), these prototypes can be detected with prospective models taking into account the complex system behaviour. But also, non-conventional methods, such as participatory techniques where stakeholders decision makers and modellers closely interact in the problem solving process (see e.g. Buhler *et al.*, 2002), may be of interest. The main challenge to build this kind of models is to combine the sparkling ideas picked up in participatory processes with a sound theoretical and operational model practice.

The dissertation can be concluded with the words of Howitt (2005): "Selection of the best model for the research task at hand is an art rather than a science. The model builder is constantly balancing the requirements of realism that complicate the model specification and solution against the practicality of the model in terms of its data and computational requirements. There is no ideal model, just some that are more manageable and useful than others."

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Summary

The growing interest in policy support oriented research in agriculture originates from the need for policy makers of making quickly good decisions in complex situations. The dissertation focuses on some recent developments of farm-level mathematical programming models as one type of quantitative models that can be used as a tool for agricultural policy support. Mathematical programming (MP) has become an important and widely used tool for analysis in agriculture and economics, because MP models offer unique advantages over other methods of agricultural sector analysis being able to address the multivariant and highly interlinked nature of agriculture (Hazell and Norton, 1986).

The dissertation distinguishes three main types of MP models. The first type of models that is developed and often applied belongs to the normative mathematical programming (NMP) approach. During the 90's positive mathematical programming (PMP) has become an important tool for policy analysis. More recently, the attempt to combine econometrics and mathematical programming models leads to a new field of empirical investigation, what we would like to name econometric mathematical programming (EMP).

In the NMP models parameters of the objective function and constraints are not calibrated. NMP models do not require base data and, therefore, sufficient knowledge of the system allows the construction of an NMP model. As a consequence, NMP does not guarantee to reproduce the observed or baseline data.

In PMP models, on the other hand, some parameters are adjusted to reproduce exactly a baseline. Because this type of models is based on empirical data the method is called positive. The main purpose of this descriptive type of models is to explain producer's reactions to external changes. PMP models are therefore above all interesting for policy makers.

While in PMP models the calibration relies mainly on direct assignment rules, a new type of MP, EMP, can be distinguished where the calibration process is the result of an estimation procedure (proposed by Heckelei and Wolff, 2003). EMP is an attempt to combine the best of worlds: econometrics and programming models. EMP models benefit from the advanced techniques in descriptive analysis of econometrics while being able to introduce changes in the underlying economic structure through the mathematical programming side of the approach. These changes in economic structure have been increasingly important in agricultural policy analysis, for example, due to the recent policy developments of price support to coupled direct payments and finally to decoupled direct payments. Also other policy instruments such as production quota, cross compliance elements, fallow restrictions and environmental constraints are quite easy to introduce in a programming model.

The combination of econometrics and programming models is certainly not new. In order to obtain more realistic simulation behaviour, the objective function or the constraints are often supplemented by external estimated functions or parameters. This can, however, introduce however difficulties or even inconsistencies (Heckelei, 2002). The most obvious example of such inconsistencies is the use of external estimated supply elasticities to build a supply function in a programming model. If this supply function is combined with other constraints in one programming model, the simulation results will not reproduce the original external estimated supply elasticities. There exist approaches for getting round this problem (Heckelei, 2002), but it is often more useful to apply directly EMP.

EMP is based on the idea of using the set of first-order optimality conditions of the final simulation model as estimation equations. The parameter estimates will be in line with the simulation model and, therefore, inconsistencies are avoided.

The objectives of this dissertation are to describe these three types of MP models in detail, to develop tools for agricultural policy support based on the three types of MP and to apply the developed tools on specific cases. The applications should prove the utility of the models for policy analysis and can lead to policy recommendations, but these recommendations themselves do not form topics for the main conclusions of the dissertation. Instead, the strengths and weaknesses of the different models are reviewed and compared according to the dimensions of the applications such as the purpose of the model and the intended users. The model reviews lead to recommendations for the selection of methods for a research task at hand. The choice of method depends mainly on data availability and model focus.

For a new policy, radically different from the previous, less data are available and therefore more normative techniques have to be used. Data availability remains a major prerequisite for applying PMP and EMP. When no empirical data are available, an MP model will inevitably rely on an NMP technique. In EMP, the combination of econometrics and programming may help to take full use of the scarce available data.

The model focus can be prescriptive, explorative or descriptive. A model intended for prescription can only rely on NMP. NMP can also be very useful for demonstration of sensitivity and for gaining insight in a problem. Therefore, NMP is suited for explorative research of new opportunities and innovations within a context of resource constraints. PMP and EMP on the contrary, will be preferred for description and prediction of behaviour and reactions on modifications in existing policy instruments.

Generally, EMP should be more robust and theoretically correct than PMP due to the advanced techniques of descriptive analysis of econometrics. However, the application of EMP has shown that the development of an EMP model requires more resources for data collection and for numerical solving the problem. Currently, EMP is only applied yet to problems with a limited size and complexity.

Samenvatting

De stijgende interesse in beslissingsondersteunend onderzoek in de landbouw vloeit voort uit de behoefte van beleidsmakers om snel goede besluiten te nemen in complexe situaties. Deze verhandeling behandelt een aantal recente ontwikkelingen van bedrijfsspecifieke mathematische programmeringsmodellen als één type van kwantitatieve beleidsondersteunende modellen. Mathematische programmering (MP) is een belangrijk en veel gebruikt hulpmiddel voor analyse in landbouw en economie geworden omdat het unieke voordelen biedt t.o.v. andere methodes door de mogelijkheid om de complexe interacties relatief eenvoudig te beschrijven (Hazell en Norton, 1986).

Deze verhandeling onderscheidt drie belangrijke types van MP modellen. De eerste ontwikkelde MP modellen behoren tot het type van Normatieve MP (NMP) modellen. Tijdens de jaren '90 is Positieve MP (PMP) een belangrijk hulpmiddel voor beleidsanalyse geworden. Recentelijk, heeft de combinatie van econometrie en MP geleid tot een nieuw domein van empirisch onderzoek, in deze verhandeling econometrische MP (EMP) genoemd.

In NMP worden de parameters van het model niet geijkt. De ontwikkeling van NMP modellen vereist daarom geen empirische gegevens. Voldoende kennis van het systeem volstaat voor de bouw van een NMP model. NMP garandeert daardoor echter niet dat een referentiesituatie kan gereproduceerd worden.

PMP modellen gebruiken ijking om bepaalde parameters aan te passen zodat een referentiesituatie precies wordt gereproduceerd. Het belangrijkste doel van dit type van modellen is de beschrijving van reacties van landbouwers op externe veranderingen. PMP modellen zijn daarom in de eerste plaats interessant voor beleidsanalyse.

In tegenstelling tot PMP, waar de ijking gebaseerd is op vergelijkingen zonder vrijheidsgraden, wordt in EMP geijkt met een schattingsprocedure. EMP is een poging om het beste van econometrie en MP te combineren. EMP benut de voordelen van de geavanceerde technieken in beschrijvende analyse van econometrie terwijl ook veranderingen in de onderliggende economische structuur in het model kunnen gebracht worden via MP. Deze veranderingen in economische structuur worden steeds belangrijker in landbouwbeleidsanalyse omwille van de recente nieuwe beleidsinstrumenten die steun loskoppelen van productie. Ook andere beleidsinstrumenten zoals productiequota, randvoorwaarden (cross-compliance), braakverplichtingen en milieubeperkingen zijn gemakkelijker in een MP model te introduceren dan in andere types van modellen.

De combinatie van econometrie en MP is zeker niet nieuw. Om realistischer simulatiegedrag te verkrijgen, worden de objectieffunctie of de beperkingen vaak aangevuld door externe geschatte functies of parameters. Dit kan echter moeilijkheden of zelfs inconsistenties introduceren (Heckelei, 2002). Het duidelijkste voorbeeld van dergelijke inconsistentie is het gebruik van extern geschatte aanbodselasticiteiten om de parameters van een aanbodsfunctie in een MP model te kwantificeren. Door de combinatie van de aanbodsfunctie met bijkomende beperkingen in een MP model, zullen de simulatieresultaten niet de originele extern geschatte aanbodselasticiteit reproduceren. Hoewel het mogelijk is om dit probleem te omzeilen (Heckelei, 2002), is het toch nuttiger om rechtstreeks EMP toe te passen. EMP is gebaseerd op het gebruik van de optimaliteitscondities van het MP model als basisvergelijking voor de schattingsprocedure. Het model met de geschatte parameters reproduceert daarom altijd de geobserveerde gegevens en inconsistenties worden vermeden.

De doelstellingen van deze verhandeling is het beschrijven en toepassen van deze drie types van MP modellen. De toepassingen illustreren het nut van de modellen voor beleidsanalyse en kunnen tot beleidsaanbevelingen leiden. Deze aanbevelingen vormen geen onderwerp voor de eindconclusies van de verhandeling.

In plaats daarvan, worden de sterke punten en de zwakheden van de verschillende modellen vergeleken. Dit overzicht moet leiden tot aanbevelingen voor de selectie van de juiste methode voor een specifieke onderzoeksopdracht. De keuze van methode hangt hierbij hoofdzakelijk af van gegevensbeschikbaarheid en de focus van het model.

Voor een nieuw beleid, sterk verschillend van het vorige, zijn uiteraard minder gegevens beschikbaar en daarom moeten meer normatieve technieken worden gebruikt. De beschikbaarheid van gegevens blijft immers een belangrijke eerste vereiste voor het toepassen van PMP en EMP. Wanneer geen empirische gegevens beschikbaar zijn, zal MP zich onvermijdelijk op een NMP techniek moeten baseren. In EMP, kan de combinatie van econometrie en MP bijdragen tot een optimale benutting van de beperkte gegevens.

Ook de focus van het onderzoek - prescriptief, verkennend of beschrijvend - bepaalt mee welk type model het meest in aanmerking komt. Een prescriptief model kan enkel via NMP. Ook voor verkennend onderzoek kan NMP zeer nuttig zijn bij het creëren van inzicht in een probleem en het onderzoeken van nieuwe kansen en innovaties binnen een context van beperkte middelen. PMP en EMP zullen echter meer verkozen worden voor de beschrijving en voorspelling van gedrag en reacties op wijzigende externe omstandigheden. Over het algemeen zou EMP robuuster en theoretisch correcter moeten zijn dan PMP dankzij de geavanceerde technieken van beschrijvende analyse van econometrie. De EMP toepassing heeft nochtans aangetoond dat de ontwikkeling van een EMP model meer middelen voor gegevensinzameling en voor het numeriek oplossen het probleem vereist. Momenteel, kan EMP daarom enkel toegepast worden op problemen met een beperkte grootte en complexiteit.

Scientific curriculum vitae

Jeroen Buysse was born in Eeklo on June 3, 1978 and has followed secondary eductation at the Sint-Vincentiuscollege in Eeklo. In 2001, he has received the degree of Bio-engineer in Agricultural Sciences at Universiteit Gent. In 2006, he has also successfully finished to doctoral training program.

In August 2001 he has started as scientific researcher at the department of Agricultural Economics, Faculty of Bioscience engineering, Universiteit Gent. First, from August 2001 to February 2002, he has worked on a bio-economic simulationproject of Flemisch dairy farms in collaboration with the Department of Applied Mathematics, Biometrics and Process Control. From February 2002 to May 2006, he has collaborated in the SEPALE project (System for Evaluation of Agro- and Agro-environmental Policies) together with CLE and UCL. From October 2005 to October 2006 he has also been involved in a project to develop a model for waste management.

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