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KRAM - A Sector Model of Danish Agriculture: Background and Framework Development

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Abstract
This paper outlines a new spatial, nonlinear, programming model of the agricultural sector in Denmark. The KRAM model (KVL's Rationalized Agricultural Model) optimizes production functions on a very disaggregated level, allowing for analysis of changes in physical constraints to production, as well as price changes. The model is dynamic, with a time horizon of 10 years. The structural development is determined endogenously using profits and a Markov chain model. The purpose of this paper is to place KRAM in a theoretical framework; future work will address the programming, calibration, and application of KRAM.

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Abbreviations

AAGE:	Agricultural Applied General Equilibrium model
ADAM:	Annual Danish Aggregated Model
CAP:	Common Agricultural Policy
CGE:	Computable General Equilibrium
DIAFE:	Danish Institute of Agricultural and Fisheries Economics
ECU/Euro:	European Currency Unit, now replaced by the Euro
ESMERALDA:	Econometric Sector Model Evaluating Resource Application and Land Use in Danish Agriculture
ESU:	European Size Unit
FAPRI:	Food and Agricultural Policy Research Institute
FASSET:	Farm ASSEsment Tool
GAMS:	General Algebraic Modelling System
GESMEC:	General Equilibrium Simulation Model of the Economic Council
KRAM:	KVL's Regionalized Agricultural Model
KVL:	Royal Veterinary and Agricultural University
LP:	Linear Programming
PMP:	Positive Mathematical Programming

Abstract

A model of the Danish agricultural sector named KRAM (KVL's Regionalized Agricultural Model) is developed in this paper. KRAM can be described as a spatial, dynamic, nonlinear, programming sector model. KRAM's purpose is to make policy analysis in the complex market conditions Danish agriculture is working under today. In order to do this in the best possible way the model optimizes the production functions on a very disaggregated level. This allows for analysis of changes in physical constraints to production, as well as price changes. The model is capable of calculating some environmental effects of agricultural production, and provides detailed spatial description of the agricultural economy and production. The time horizon is 10 years, and the model allows farms to develop during those years both in terms of investments on the farm, and in terms of the number of farms in different farm groups. The structural development is determined endogenously using profits and a Markov chain model.

The main purpose of this paper is to outline the model, and place it in a theoretical framework. KRAM will be programmed in a set of smaller submodels, in order to ease the implementation of new features. The open structure also reduces the demand for computation power, and reduces the solution time significantly. Later papers will look into the programming, calibration and application of KRAM.

Keywords: Agricultural production, positive mathematical programming, dynamic agricultural sector model, regions, Markov chain, structural development, crops, pigs, cows, GAMS.

1 Introduction

In the industrialized countries there is a long tradition of intervening in the agricultural economy and production. Some of the traditional reasons have been the need for securing farmers a fair income, or an interest in maintaining an active population outside the cities. More recently the public interest in production methods and animal welfare has propelled new interventions.

As a result of public interference in the agricultural market, the need for knowledge about the effects of further restrictions has been both more relevant and troubled: More relevant, as there always seems to be a new policy related to agricultural production under way, and more troub-led, as the existing market distortions make analysis difficult. One way of making policy analysis in circumstances like this is to construct computer models of the agricultural sector.

There has been such an agricultural sector model at the Royal Veterinary and Agricultural University since 1973 called the KVL model. The latest version of the KVL model is from 1992. Since then most of the data used are not produced any more, and numerous new needs for calculations have arisen where the old model is not suitable. This paper describes a new model, called KRAM for KVL's Regionalized Agricultural Model, of agricultural production and economy capable of solving these new issues, dealing with present market distortions and predicting the outcome of new ones. KRAM's main purpose is to answer what-if questions about policies affecting agriculture, whether they are support policies, taxes or physical constraints to production such as N-quotas or limitations to farm size.

The whole model is developed as a combination of several Ph.D. projects at the Department of Economics and Natural Resources at the Royal Veterinary and Agricultural University, Copenhagen. This paper has been written during my stay at the Center for Agricultural and Rural Development at Iowa State University during the first half of 1998. Model description, building, calibrating, and applying the model will form the rest of my Ph.D. dissertation when I return to Copenhagen.

2 Choice of model type

There are a number of possible ways to model the Danish agricultural sector. On a very general level the choice is between an econometric model and a programming model. Both generic model types can be refined, and some combinations are also possible. The choice of model type has significant implications for output. Each has strengths and weaknesses, and the choice of model therefore must be based on the specific type of calculations it is going to make. The model must be firmly rooted in economic theory, and at the same time describe as accurately as possible the actual production possibilities and constraints in Danish agriculture.

KRAM's main purpose is to solve what-if-questions: questions that arise when new policies are considered, or when the current development attracts public interest. In order to build KRAM, we have to define exactly which parameters the model should calculate. Here is a list of non-ranked "wishes." They originate from discussions both within the department and with other institutions[1] about what is interesting and important, in light of the current development in research, agriculture and politics.

- Base the model on recognized economic theory. Include all known current and already ratified future policy actions.
- Create detailed calculations of agricultural production on farm, regional and national levels using both amounts and prices in the calculations. Formulate as a bottom-up model, with different farm types and regions based on average numbers from empirical data. Farm types must be divided by type of production and by economic size. Include organic farm types.
- Describe soil types in the model, either as different soil types in each farm type, or as a clever regionalization of the model to keep the regions' soil types homogeneous.
- Describe in detail the major crops' production functions, using nonlinear response functions for cash crops for fertilizers, manure and pesticides, and their interactions. Use nonlinear response functions for some other crops. Create a realistic model for crops rotation. Use Positive Mathematical Programming for distribution of crops (Howitt, 1995).

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[1] The Danish Environmental Research Institute and the Danish Institute of Agricultural and Fisheries Economics.

- Detail the production functions for livestock. Link to crops both in relation to feed demand and manure supply as well as endogenous trade with piglets and manure. Possibly include several different production functions for identical livestock.
- Include dynamics, along with estimates of structural development as a function of relative profitability. Change production technology over time and include uncertainty in production. Optimize production on the basis of expected prices with a time horizon of 10 years.
- Provide endogenous prices for goods traded between farms, and some others, as well as exogenous prices for all other goods.
- Calculate leaching of nitrogen into the water environment. Calculate emissions of methane and nitrous oxide.
- Keep data separated from the equation part of the model, in a handy format (spreadsheet?). Import data into the model when solving it. Furthermore, it is really important that data are easy to update. Formulate the model as a set of smaller submodels, in order to reduce solution time, and to make solution of very nonlinear problems possible.
- Keep the model easily extendable if additional analysis is wanted later.

The problem is now constrained to find the theoretically best model to fulfill these wishes, and sketching such a model. That is the focal point of this paper.

2.1 Methodology

Consider the following example[2]: A man is dropping an iron ball from a railroad bridge down upon a concrete highway. He repeats the experiment several times, always observing the same result. He concludes that iron balls tend to move from railways tracks to concrete highways. The model he builds can predict accurately what is happening, as long as nothing is changed outside the model. But the day he tries to predict what will happen, if he drops an iron ball from a railway to the concrete highway on the bridge just upon it, he will find that the model was not firmly rooted in physical theory.

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[2] The example is gratefully borrowed from Holcombe (1989).

This story illustrates the need for putting research into an established framework in order to minimize the risk of errors. The obvious economic example is the Phillips curve (Phillips, 1958), which until 1970 predicted the relationship between unemployment and inflation very well. But as decision makers started to use the Phillips curve, and wanted to use the tradeoff between inflation and unemployment, it didn't hold any more. The well-known result was stagflation. It was only valid as long as decision makers didn't know about it. The Phillips curve was a statistically observed macroeconomic relationship, without roots in microeconomics, and without assumptions on individual behavior (Bleaney, 1991; p. 147). So even if the invention of the Phillips curve triggered many additional findings, you wouldn't want to build a model on assumptions like that. In order to yield consistent results over a period of time the model must be based on proven[3] assumptions about individual behavior and relationships. It is not sufficient to judge the model solely on its predictive power.

Furthermore, the assumptions of what is exogenous in the model are critical, yet it is absolutely necessary to make such assumptions. Apart from the fact that it would be impossible to build a model with all the features of the real world, such a model would be just as confusing to observers as the real world itself. A model is more like a map, where you illuminate the things you need for your own specific purpose (Holcombe, 1989; p. 13).

As the model has to exclude some (potentially important) factors of the economy, it cannot make correct predictions in all circumstances. The goal is then to try to exclude only the unimportant parts of the economy. This is, in some sense, a bad thing about models, but Professor Ellen Andersen may be accurate in her description of the ADAM[4] model in Dam (1996): "*The model is not clairvoiant; its predictions are based on knowledge about past economic facts, which are embodied in the model equations. Before one wishes differently, one should consider the consequences of the wish being granted.*"[5]

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[3] Theory of science positivists claim nothing can be proven, only falsified (Kragh and Pedersen, 1981). Recognizing that fact, the neoclassical microeconomic theory with extensions is the best guess of the truth we possess right now, and will be used as the theoretic basis here.

[4] Annual Danish Aggregated Model.

[5] My own translation from Danish.

2.2 Theoretical description of model types

In order to establish a basis for choosing the right type of model, some relevant model types should be examined.

2.2.1 The CGE model

One choice of model could be a Computable General Equilibrium (CGE) model. A CGE model is very ambitious because it attempts to establish the complete vector of final consumption and production using only a list of the commodities, the technology, preferences and endowments (Mas-Colell *et al.,* 1995; p. 511). Since a CGE model is a *general* equilibrium model, all sectors in the economy must be represented. Therefore, a CGE model of the agricultural sector would imply modeling at least one more sector, the rest of the economy.

The normal way to analyze agricultural issues is to take an already established CGE model of the overall economy, and enlarge the agricultural section. An example is the Danish AAGE model (Frandsen *et al.*, 1994), which is based on the GESMEC model (Frandsen *et al.,* 1996).[6]

A CGE model is especially well-suited for aggregate, descriptive analysis of agricultural production as a response to price changes, and the agricultural sector's interrelationship with other sectors, domestic or abroad. It usually does better at finding the problem's long-run equilibrium, than the path the economy will actually follow to get there. As a top-down model, it is not quite as well suited for analysis of changes in physical production constraints, as models containing the underlying production functions. Disaggregated analysis is also difficult.

2.2.2 Econometric optimization models

Another way of modeling the agricultural sector is to use optimization models. That may be a programming optimization model[7] or an econometric optimization model.[8] An econometric model is here defined as a set of statistically estimated functions representing some part of soci-

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[6] AAGE: Agricultural Applied General Equilibrium model, GESMEC: General Equilibrium Simulation Model of the Economic Council. Other agriculture-oriented CGE models are described in Frohberg (1993) and Penson and Chen (1993).

[7] In the following simply a programming model.

ety, but either including some but not all other sectors, or simply with only one sector represented in the model.[9] This could, for instance, be an estimated translog profit function for the whole agricultural sector. The programming model is defined as a set of production functions and constraints. That is typically as disaggregated as a production function for each crop on each farm type in each region. Programming models have often been LP models. The two approaches are clearly different.

The strengths of an econometric model are primarily to show the sector's response to price changes and for descriptive analysis. In comparison to a programming model the strength of being able to estimate the functions statistically and provide a confidence interval is important. This type of model is typically much more detailed in the description of the sector than a CGE model. Since the underlying production functions are not explicitly in the model, problems are created in some of the same fields as the CGE model, especially in modeling changes of physical constraints to production. Furthermore, the fact that both programming and econometric equilibrium models do not contain information on feedback from other sectors may be a source of error.

2.2.3 Programming optimization models

The programming model approach is the most widely used in agricultural sector modeling. The traditions date back to the first LP sector model by Henderson (1959)[10] and the much larger recursive LP sector model by Day (1963). Since then, agricultural programming models have been used in many studies.[11]

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[8] In the following simply an econometric model.

[9] The obvious Danish agricultural example is the ESMERALDA model (Econometric Sector Model Evaluating Resource Application and Land Use in Danish Agriculture) (Jensen, 1996), which is a set of translog profit functions estimated from farmers accounts. Foreign examples are Ray (1993) and Taylor (1993).

[10] Henderson's model included only a few crops and no livestock, but it was the first to calculate aggregate supply response using a programming model.

[11] As for instance in (Andersen *et al.*, 1974; Andersen and Stryg, 1976; Meister *et al.*, 1978; Bauer, 1989; Bauer and Kasnakoglu, 1990; Stryg *et al.*, 1992; Apland and Jonasson, 1992; Horner *et al.*, 1992; Hoveid *et al.*, 1993; Frohberg *et al.*, 1993; Stryg *et al.*, 1995; Hoveid, 1995; Pomarici and Hanf, 1996; Jonasson and Apland, 1997; Vatn *et al.*, 1997; Helming, 1997)

These models are primarily based on a linear programming approach with some refinements. Some are recursive linear programming models, some have nonlinear elements, and a few have so many other submodels that the LP part becomes a minor part of the model. Mixing different model types into one big model makes it difficult to establish when a model is a programming model and when it is an econometric model. But apart from the problems of assigning a model class, this may improve the quality of the models immensely. By using the best of both the programming and the econometric approaches, one may actually be able to include the good and get rid of the undesirable features of both model types (Bauer, 1989).

The strength of a programming model is mainly in normative analysis. It is good at telling what should be done (in order to maximize profits) but weaker when predicting what will actually happen. Unlike the other model types, programming models are strong in analyzing the effects of changes in physical constraints. They are less strong in estimating the effects of price changes, bearing in mind that linear models tend to produce corner solutions. Programming models use both amounts and prices, whereas CGE and econometric models often use only prices. Due to the duality between profit functions and the production possibility set (Färe and Primont, 1995), this doesn't affect the modeling of farmers' behavior, but it opens up possibilities for analyzing externalities in programming models. Therefore, the programming model approach is better suited for analyzing environmental effects of agricultural production.

As for the econometric models, there is no endogenous connection to other sectors, which implies a possible loss of feedback effects.

2.3 Distribution of responsibilities

Another factor, which is just as important as the theoretical choice of model, is to make sure that the wheel isn't reinvented. At present, there are at least two important models of the Danish agricultural sector, namely the CGE model AAGE and the econometric model ESMERALDA. As it is described in Kærgård *et al.* (1997), there is certainly a need for another model. In comparison to the existing models, a programming model using both amounts and prices could potentially enhance the capabilities for environmental analysis, and improve the analysis of changed physical constraints. The other models are on an aggregate level, leaving room for KRAM to tell about regional differences.

2.4 Choice of model

For the reasons just enumerated, KRAM will be a dynamic, bottom-up, programming model with some additional econometric submodels. There should be a number of regions with relatively homogenous soil types. In each region there will be a number of farms groups, estimated from empirical data, and separated by main source of income (such as pork, milk or crops), economic size (measured in Economic Size Units (ESU)), and whether they farm organically.

Using several submodels instead of one large model will improve the ability to solve highly nonlinear problems. It will also make addition of new modules less complicated. This model type is strong when modeling the basic optimization of farm profits, and it is easily aggregated to the necessary level. The regional and structural disaggregated description of farms and the detailed characterization of the production functions are a great advantage when modeling the agricultural production's influence on the environment. It will also be relatively easy to model new government interventions, whether they are price changes or production restrictions.

3 The new model

Bearing the wishes for the model's use in mind the following very general structure is proposed (Figure 3.1). Although this model is new, it is created with inspiration from Bauer (1989) and Pomarici and Hanf (1996). The detailed description below includes the description of each submodel, its purpose, the theory behind it, the proposed way to solve it, the data needed, and possible data source(s). In general the model is divided into regions, and within each region some different types of farms are represented (e.g. a pork farm with a turnover of more than 100 ESU = 120,000 ECU). They are defined as *farm groups* in KRAM. If the number of regions is multiplied with the number of *farm groups*, the number of *farm types* in the whole model is achieved.

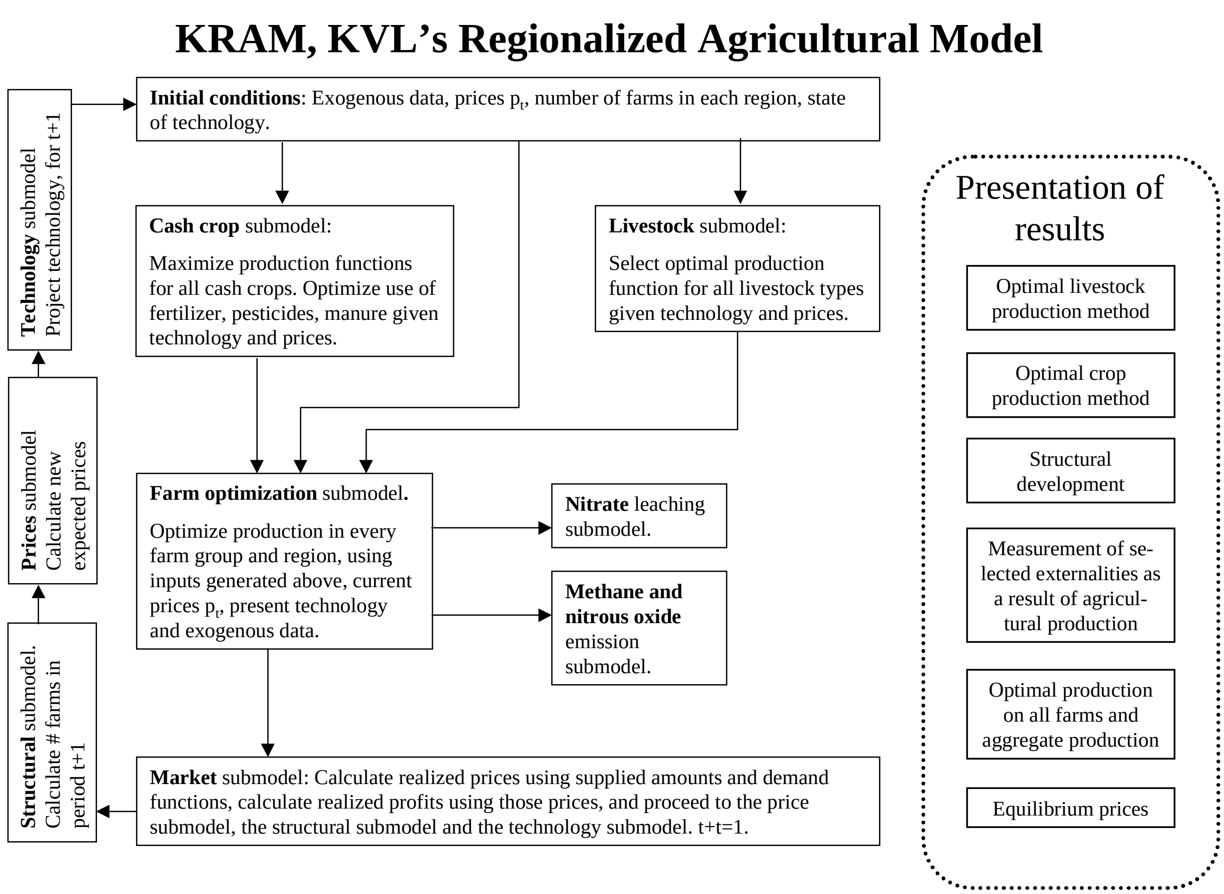

Figure 3.1. Outline of the KRAM model.

3.1 Initial conditions

This submodel contains all data necessary for making the calculations in KRAM, including all possible production functions at the current technology, the expected price matrix, the current state of structural development (i.e., the number of farms in each farm group and region), restrictions on production from legislation, and identification of the time period. These data are exogenous in the first time period, while forthcoming periods' data are generated endogenously.

3.2 Cash crop submodel

The cash crop submodel optimizes application of fertilizers, pesticides and manure, using expected prices and expected manure available for all cash crops at all farm types in all regions. Since this optimization is not within the farm optimization model, the best prediction of available manure has to be used. After calibrating the model this should not be a problem. The reason this optimization is not done within the farm optimization model is that it would be difficult to solve that very nonlinear problem, a point proven by Hasler (1998). The optimization problem is to find the application of nutrients and pesticides that equalizes marginal profit to marginal cost for each input. The optimum yield and input use is forwarded to the farm optimization model as a linear production function, without any loss of generality.

The calculations are similar to those of Kesting (1997) and Hasler (1998). Research is currently under way to find the combined influence of pesticides and nutrients on crops, and the results from this research will enter the model when ready.

Feed crops, such as grass for silage and fodder beets, pose a special problem. These optimization problems are not profit maximization problems, but constrained cost minimization problems. Constraints are the amount of feed needed and the alternative income (shadow price) on a hectare. The first will only be known when the number of animals and their optimal use of feed can be calculated. Calculation of the latter needs knowledge of both the profits from alternative crops and the possibilities in the crop rotation scheme. Both factors can only be calculated in the farm optimization submodel. So in order to calculate the use of inputs for the feed crops consistently, they have to be optimized in the farm optimization submodel.

The calculation for the organic farms is an easier problem to solve than traditional farms, since no use of pesticides or artificial fertilizers is allowed. They will have to distribute the available manure to the crops in an optimal way, equalizing marginal revenue from manure for each crop.

The data needed are production functions for the crops, split to reflect differences between regions (i.e., different soil types), and, if relevant, also the differences between farm groups. Both were considered necessary in the last KVL model (Stryg *et al.*, 1995). In Statens Jordbrugs- og Fiskeriøkonomiske Institut (1998c) data are available for spring barley, winter barley, winter wheat, rye, rape seed, grass seed, potatoes, peas, sugar beets, fodder beets, grass and green fodder, and set-aside. The data for the crops measure past use of different inputs, but no functions of the effect of inputs are provided. Those functions can be found at the Danish Institute of Agricultural Sciences.

3.3 Livestock submodel

In a way similar to the cash crop submodel, this submodel selects the best production technology for each livestock type. Depending on the data available this may be nonlinear equations where the optimal amount of feed is found by maximizing profits. If the data only allow a choice between different linear fodder plans, this submodel will be canceled and those plans will be transferred directly to the farm optimization submodel.

This submodel is one of the parts of KRAM that can be extended at a later time. Presently, the purpose is to show that these calculations are possible in KRAM.

3.4 Farm optimization submodel

This is the ever-beating heart of KRAM. All information generated in the cash crop submodel, the livestock submodel, and data from the initial conditions are assembled here, and used to calculate the optimal production of year *t*. A maximization problem for one representative farm of each farm group in each region is formulated and solved.

3.4.1 Optimization criteria

Which optimization criteria the model should use is a critical question. Possible candidates are profit, expected profit, the sum of consumer and producer surplus, farmers' utility, or the E-V criterion.

Simply maximizing profits would not fulfill the purpose. Farmers have a large time span between making the production decision and selling the good, and prices can change during that time. Therefore, expected profit is superior to profit as an optimization criterion. Furthermore it works with PMP, which the E-V criterion doesn't. It is therefore a strong candidate.

The Marshallian surplus, or the sum of consumer and producer surplus (Mas-Colell *et al.,* 1995; p. 331), is used in many models, especially in CGE models. However, the Marshallian surplus does not express the incentives for a single farm correctly, since increased consumer surplus may involve costly actions at the farm level. An example is animal welfare, which has a value for consumers. If the Marshallian surplus were used, the overall community welfare would be maximized, but it is probably fair to assume that farmers worry more about profit when planning production. Therefore maximizing profit does not yield the same result as maximizing Marshallian surplus. And since KRAM is supposed to model real farmers' behavior, it would be wrong to use Marshallian surplus as optimization criterion. Note that if prices were reflecting consumers' preferences correctly there would be no difference between the two.[12]

Using the expected utility as the optimization criterion is a very interesting possibility. However, the standard problem of assigning utility values to production also applies here. One solution could be simply to define the utility of an activity as the profit when possible, and some number when the activity doesn't yield profit, e.g. job satisfaction or working environment. But how much utility is it reasonable to assign to job satisfaction? And is that number the same for all farmers? Does the utility derived from the working environment vary with the debt ratio? That

[12] This is actually only true if prices are constant, since profit maximization otherwise would encourage monopolistic behavior. But since farmers in KRAM plan production on the basis of expected prices, then prices are taken as constant by farmers. The fact that they are derived from non-trivial demand functions is not used by farmers in KRAM.

type of questions remains hard to answer, and for that reason the expected utility option is not chosen. However, it is clear that introducing farmers' utility as the optimization criterion could potentially enhance KRAM's description of farmers' behavior.

The E-V criterion is also a very interesting possibility. It assigns variance and covariances to the different branches of productions, and thereby a measure of the risk taken by the farmer can be calculated. A money value of this risk can be deducted from the expected profit, and in this way the farm is forced to take account of risk (Freund, 1956; Hazell and Norton, 1986). This seems to be a very good approximation of farmers' behavior. The reason it will not be used here is that the E-V criterion can not be used together with PMP. They both try to adjust the distribution of crops on the farm, and using them on the same time would cause both to fail. And since PMP is needed in the model for other good reasons, E-V has to be left out of account.

The conclusion is that KRAM will use expected profit as the optimization criteria. Expected prices will be used for planning production, and realized prices used for selling the goods. The calculation of expected and realized prices is discussed in section 3.10. Depending on the data the optimization criterion may actually change from expected profit to expected profit before tax, interest and depreciations, or something similar. This will not change the optimal solution.

3.4.2 The optimization problem

Most of the optimization problem looks like a normal LP problem, but some parts are nonlinear. One is the distribution of crops, where PMP is used. Another part is the use of fertilizer in non-cash crops. Other nonlinear parts have deliberately been removed from this submodel in order to improve the solvability. An example is the calculation of externalities, which are highly nonlinear.

The constraints for each farm firm model are available land, size of stables or milk quota, crop rotation constraints, and current policy constraints. The trade with manure has to be in equilibrium on a regional level. There is no need for a land constraint on a regional level, since this is taken care of in the structural submodel. On a national level market equilibrium for trade with piglets (and calves?) is enforced. The output from the submodel is a netput vector and a price vector from each farm type. This is convenient, since we are working with expected prices. When the realized profits are wanted the expected prices will be replaced with the new equilibrium prices, and the solution is merely a question of multiplying two vectors.

Finally, the optimal demand and supply are aggregated to the regional and national levels by summing the netput vectors, and multiplying with the state of the structural development. In the case of goods traded between farms, the numerical values of the netput values are summed, and the result divided by two in order to get the traded amount.

When the optimization model is going to be built, it will probably be based on the FASSET model currently developed at KVL and DIAFE. FASSET is a three-period farm optimization model, which has numerous updated data on rotation of crops, pesticides, nutrient carryover effects, and nitrogen leaching. This model was originally developed in Dalsgaard (1997) as part of the project “sustainable strategies in agriculture.”

3.4.3 Positive Mathematical Programming

The PMP approach calibrates the model, such that the model’s forecast of crop distribution is in accordance with empirical observations, without imposing any other flexibility constraints. PMP imposes decreasing marginal profit on crops, using a quadratic function of their area. That the marginal profit decreases with larger area can be regarded as an aggregation of all the restrictions not explicitly in the model already. In a normal optimization model, some crops will not be grown. This is never observed in the real world, where all crops are actually grown, even if other crops would have yielded a higher profit. The reason doesn’t have to be irrational farmers. It could be less than perfect knowledge about expected yield and variation. It could be disease control getting more costly, if you don’t rotate crops. It could even be displeasure from having only one crop, or need for a little hay for horses.

With PMP this is aggregated to reduce a crop’s profit with its area. Optimum is found where the marginal profits of land from all crops are equal. The model can easily be calibrated to any observed crop distribution. When using PMP, if a crop’s price is increased, its area will also increase, but only until the marginal profit of land for all crops is equalized again. This process ensures a smooth adjustment of crop distribution to relative profitability, and limits the number of flexibility constraints needed. The PMP model needs to be calibrated. This process has been described in Horner *et al.* (1992) and in Howitt (1995). The calibration has to take place in a separate model, and can only be done after the results from the cash crop and livestock submodels are ready. This separate model is not displayed in Figure 3.1, but will technically be within the farm optimization model.

KRAM will use PMP to replace flexibility constraints imposed on crops, but not other places in the model. Other models, such as the Dutch DRAM model (Helming, 1997) have also used PMP to replace constraints on livestock production. This will not be attempted here, because this model is more disaggregated. The constraints on livestock in KRAM are derived in section 3.8.4.

3.4.4 Number of regions

One crucial question is how many farm types there should be in the model. Ideally, one would divide the country into regions with homogenous soil types and within each region a farm type for each type of production. That could potentially amount to many farm types. Data availability does, however, put a strict limit on what is possible without harming how representative data are. The latest model of the Danish agricultural sector had 39 farm types (Stryg *et al.,* 1995). According to DIAFE, at least 20 farms are needed in each group in order to make a representative average. The whole statistic is based on about 2,000 farms (Statens Jordbrugs- og Fiskeriøkonomiske Institut, 1998c), and since some areas are better represented than others, the maximum number of groups will be between 40 and 50.

The optimal solution is probably to have just enough regions to represent soil types in a satisfactory way and then get as many farm types as possible. Seven regions and seven farm groups within each region yielding a total of 49 farm types seems to be reasonable, but further analysis is needed.

This submodel obviously needs a lot of data. Most of these data can be compiled from the original data behind Statens Jordbrugs- og Fiskeriøkonomiske Institut (1998c), and Statens Jordbrugs- og Fiskeriøkonomiske Institut (1997). Data on organic farms are available from Statens Jordbrugs- og Fiskeriøkonomiske Institut (1998b) and data on prices can be obtained from Statens Jordbrugs- og Fiskeriøkonomiske Institut (1998a). Some other data are at Denmark's Statistics, and some at the Danish Institute of Agricultural Sciences.

3.5 Nitrate leaching submodel

This submodel is an example of how externalities can be calculated within KRAM's framework. Nitrate leaching is used, since it has received considerable attention during the last decade. With this type of add-on, KRAM is able to calculate a large number of externalities. Since the calculations are separated from the optimizations, very heavy calculations can be completed. Should it be necessary to calculate externalities within the optimization part of KRAM, then that is also possible.

Using the optimal use of manure and fertilizers from the cash crop submodel, and the optimal crop distribution on each soil type (region) from the farm optimization submodel, this submodel calculates the resulting leaching of nitrate into the water environment. Basically, these data are simply collected from the relevant submodels, and put into the formula for nitrate leaching.

The leaching is aggregated as needed, and forwarded to the presentation submodel.

3.6 Methane and nitrous oxide submodel

In a similar way as in the nitrate leaching submodel, this submodel calculates the leaching of methane and nitrous oxide using number of animals from the farm optimization submodel, and type of fodder used from the livestock submodel. Finally, the results are forwarded to the presentation submodel.

3.7 Market submodel

In the market submodel, the goal is to find the equilibrium prices, considering aggregate demand and supply. It is assumed that all Denmark is one marketing area, and no price differentiation is needed among different regions. That implies that transportation costs are equal for all farmers throughout Denmark. Considering the geographical size of Denmark that is probably almost true.

Finally, the expected profits that were maximized in the farm optimization submodel need to be updated using the new equilibrium prices.

3.7.1 Finding equilibrium prices

From the farm optimization submodel the aggregate netput vector is ready. But the aggregate demand functions are difficult to obtain. As Denmark is a large exporter of agricultural goods, it is not satisfying to examine domestic demand only. But since Denmark supplies only a small part of the world market trade volume, the small country assumption could be used.[13] That is likely to hold as long as we are discussing products where the Danish world market share is small, like cereals or beef. But in the case of pork, butter and cheese, Denmark has a large world market share. Hence, the small country assumption is unlikely to hold. Finally, some organic goods face a very special market situation. They are typically not exported, and domestic consumer demand is shifting rapidly. An in-depth analysis of future domestic demand for organic products seems to be needed.

The butter and cheese world market prices are unstable, but the EU support system is insulating Danish milk production from world market price fluctuations. That diminishes the impact of world market changes on Danish milk producers. So in this case the small country assumption may not hold, but we still don’t need global demand functions. The relevant prices are available from the CAP budget, although it will be necessary to look back and see how those prices corresponded to Danish farm-gate prices.

In the case of pork, the situation is different. Pork producers are not insulated from world market fluctuations, and they are too important on the world market to be disregarded by the small country assumption. However, annual changes in the volume of Danish pork production have in the past been within a few percentage points. Considering the history of Danish pork production, a 3 percent change in production volume is actually a very large change. Since domestic demand is independent of domestic production, all of the 3 percent change has to be exported. Approximately 77 percent of Danish pork production is exported (De Danske Landboforeninger, 1997),

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[13] Recognizing that the Danish exports are relatively small and insignificant in the world market, the small country assumption says export prices are constant. This is the approach used in all previous KVL models.

so a 3 percent change in production would imply a 4 percent change in exports. Even if Danish exports are important on the world pork market, there is no reason to think that a 4 percent shift in Danish exports alone would shift prices dramatically. So the error of using fixed export prices is small.

Organic products pose a special problem. They are new goods with a large market share. Therefore, few data are available, and they do not necessarily have anything to do with the future market situation. Domestic *demand* for organic products is presumably going to be even more important, but the present rate of increase can’t go on for long. On the other hand, new export markets may very well open, and create opportunities for further expansion of organic production.

The *supply* of organic products is very sensitive to policy action. Presently farms are supported in the transition phase from conventional to organic farming, and get higher prices as organic farmers. Changes in this support will have a large impact on the supply of organic products. Physical constraints blocking further expansion of organic production will be more important. A more detailed analysis of organic demand and supply is certainly needed before realistic demand functions are ready.

All other goods produced by Danish agriculture are significantly less important on the world market. Without violating anything the small country principle can be applied, and forecasts of world market prices used.

KRAM is going to make forecasts for a 10-year period. That implies that forecasts of demand for agricultural goods are needed for the same time span. Estimating prices for the next 10 years, considering policy actions in all relevant import and export countries, scope of development in production techniques, and changes in consumption patterns around the world is a major job. Since many researchers around the world devote all their time and energy to estimate world market developments, there is no reason to believe it can be done better as a minor project within this study.

One of the suppliers of forecasts is the Food and Agricultural Policy Research Institute (FAPRI) at Iowa State University and University of Missouri-Columbia. FAPRI produces both expected world market prices and volumes for agricultural goods in consideration to known and expected changes in global policy actions, production development, consumption development, income development, population development and other relevant factors (FAPRI, 1998). Forecasts are calculated for each year in a 10-year period for all agricultural goods of interest to KRAM, except for organic goods. The only drawback is that the prices are not Danish farm-gate prices, but at best FOB Hamburg. For pork, the only available price is “Iowa-Southern Minnesota barrow and gilt price.” In order to use this price an econometric analysis of its relationship to Danish farm-gate prices is needed. The same problem is relevant for all other goods. Since a correlation between Danish and international prices is expected a priori, that is probably not too difficult.

One other variable that needs some attention is the exchange rate. It will generally be assumed that Denmark maintains its fixed exchange rate towards the Euro. In the cases where prices are measured in U.S. dollars (for instance the FAPRI prices) the FAPRI forecast of the dollar/euro relationship will be used.

3.7.2 Solving for corrected farm profits

Assuming an equilibrium price vector has now been found, we need to calculate the realized profits for all farms. As discussed in the price submodel section, prices are not completely identical for all farms due to quality differences, and a certain amount of economies of size when bargaining.

After identifying a price vector for each farm type, all that is left is to multiply it with the netput vector for each farm type, and to correct for fixed costs.

3.8 Structural submodel

This submodel is the trickiest in KRAM. The attempt to calculate the structural development endogenously from the results generated in other parts of the model is novel. Usually structural development has been analyzed outside models, and only applied in agricultural sector models as exogenous calculations.

A number of studies have analyzed structural development in agriculture. The definition of structural development is not always clear, and many different factors can be included, as discussed in Wiborg and Rasmussen (1997). Here, structural development will simply be defined as the development of the number of farms with agricultural production, divided into different groups as in the rest of the model.

3.8.1 Background for structural development

In general, agricultural economists will agree that the main force behind structural development is relative profitability for farms. If a farm type is consistently generating losses, it will sooner or later go out of business. Since the land will always be used, another farm will buy it. The farm capable of buying this farm has to earn a profit, so that the money is available. In this way the profitable farms will slowly absorb the other farms.

Another way of analyzing the same problem is to consider the long- and short-run cost curves. They normally look like in Figure 3.2. Farm A has larger unit costs than farm B. In the short run A has to stay on the short-run average cost curve. Therefore A is not able to move down to B, even if that would lower his unit costs. But since unit costs can be reduced by A by increasing the size of production that will be advantageous for A in the long run. If the limiting factor for achieving the lower average costs is the number of animals (and buildings to contain them), A may eventually move to B without buying another farm, and only invest in the existing farm. In that case, the number of farms is unchanged, and the structural development will be farm A moving from one farm group to another. If the limiting factor

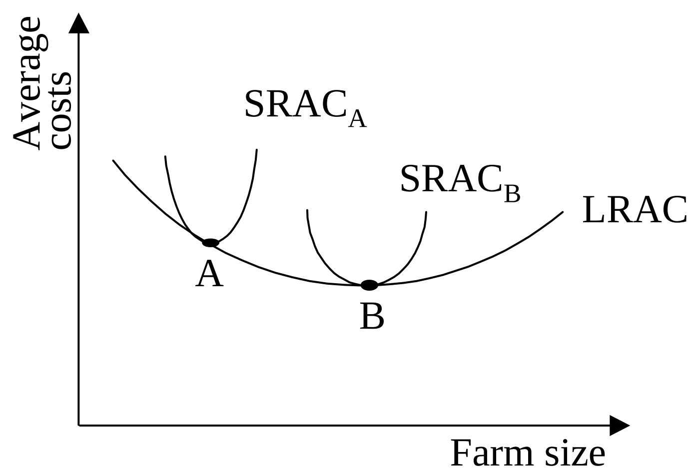

Figure 3.2. Long-run and short-run average costs.

is land, A will have to buy another farm to reach optimal size. In that case the total number of farms will be reduced, and the two merged farms may shift to another farm group.

In the long run, technological change will move the average cost curves down and to the right. That creates an incentive for both A and B to move even farther.

Finally, a number of other factors may influence structural development. An exhaustive list is impossible to compile, but all the factors mentioned here might have an impact on structural development:

- EU's Common Agricultural Policy (hectare and livestock premiums, milk quota, set aside, and the accompanying measures).
- Danish agricultural law (maximum number of farms owned, maximum number of farms rented, rules limiting farm mergers, education demands, support for young farmers, and national support to farms).
- Danish environmental law (maximum number of livestock units per hectare, and restrictions on manure disposal).
- Tax laws (inheritance taxes, capital gain tax, and depreciation rules).
- Macroeconomic factors (interest rate, exchange rate of trade partners, and supply price chocks).
- Farmers' expectations for all these.

In Wiborg and Rasmussen (1997) these reasons for structural development were analyzed using agricultural statistics from 25 years. They concluded that with the possible exception of the milk quota, the only force driving structural development is the interaction between technological change and farm's relative profitability.[14] The Danish structural development is also analyzed in Strukturdirektoratet (1998). This analysis also finds that relative profitability has a major influence on structural development, and further analysis of other factors concludes that they do have

[14] Note that this does not rule out that the factors listed here may have an impact through their influence on the profit.

an effect, but the aggregate effect is unclear. Therefore, KRAM calculates structural development using only relative profit of different farm types as the explaining variables. The underlying assumption is that all the other changes, including technological change, must show their value through the profit.

3.8.2 Method

In Rasmussen (1979), Rasmussen (1996), and Wiborg and Rasmussen (1997), Markov models have been used to estimate structural development. A later comparison of the 1979 prognosis with the actual development shows that the method is efficient in predicting structural development. For this reason, it would be interesting to let KRAM estimate structural development using a Markov model. For the reasons discussed in section 3.8.1, it is desirable to let the relative profit be the only explaining variable.

The question is, then, whether the structural submodel should estimate the transition probabilities in the Markov model directly, or use a set of transition probabilities estimated outside KRAM, and correct the results slightly using changes in relative profit from a base run. In this case the latter option is chosen. Since the Markov model has already proven its ability to estimate structural development, an exogenous estimate of transition probabilities is regarded as the best way of estimating structural development, ceteris paribus. This does not limit us from having transition probabilities changing over time. Another question is whether the regional differences in structural development are significant. If they are, transition probability matrixes will have to be estimated for each region. Otherwise, an aggregate national one will do. Further analysis will look into this. That establishes structural development in the base run.

Should a scenario mean profits different from those achieved in the base run, this must have an impact on structural development. If a specific farm type gains (loses) from the scenario assumption in relation to the other farm types, then it is assumed that this farm type will increase (fall) in number relative to base run structural development. If all farm types gain or lose with the same relative amount, the base run's structural development is maintained. Since farmers' price expectations depend on the two recent years' prices, it is natural to let their investment decisions depend on the same time span. Since investments force structural development, the estimation of structural development will also depend on the last two years' data.

This establishes the trend and the direction of the change in structural development. The following equations illustrate these concepts:

3.1 $$\Delta\Pi_{jkt} = \sum_{t=t-1}^{t}\left(\Pi_{jkt}^{S} - \Pi_{jkt}^{B}\right),$$

3.2 $$\overline{\Delta\Pi}_{jkt} = \frac{\sum_{j=1}^{n_k}\Delta\Pi_{jkt}}{n_k},$$

3.3 $$X_{jkt} = \Delta\Pi_{jkt} - \overline{\Delta\Pi}_{jkt}.$$

In all equations *j* is the farm group, *k* the region, *t* time, *S* scenario number, *B* the base scenario, and n_k the number of farms groups in region *k*. X_{jkt} is a new variable, which is used for estimating the deviations in structural development from the baseline scenario. X_{jkt} will have to be positively correlated with the number of farms in its own group. The magnitude of this relationship, and the decision to make it linear, nonlinear, or imposing an upper or lower limit, has to be made when KRAM is calibrated, as well as determining its magnitude.

Finally, some new laws may hinder structural development without affecting the profitability of the individual farm types. In Wiborg and Rasmussen's (1997) study it proved difficult to find examples, but it is not unthinkable that the current focus on sustainable farming and structural development may propel such laws. In that case, the scenario in question must implement the effects of such laws in the structural submodel.

3.8.3 Using land

One common problem of using Markov models is that there is no implicit restriction on how much land is to be used. It is unlikely that a Markov model will allocate exactly the right amount of land. Therefore, land allocation will have to be corrected. There are three different options for this:

- Change the total amount of available land,
- Change the acreage in the largest groups, and

- Change the number of farms in all groups with the same percentage until all land is allocated.

All three options are used here. The total amount of land in each region is reduced with the speed observed in the past, in order to correct for land taken from agriculture for other purposes. Second we fix the acreage for all farm types but the largest farm groups of each production type. Since the other groups have both an upper and lower limit on their (economic) size, it is not necessary to change their acreage over time. Only the largest farm group within each production branch will need to have the average land changed.

How the largest farm groups' area is changed over time will be analyzed in a later paper, and applied to the model.

Finally, the percentage of agricultural land that is now used is calculated using the new number of farms with the new acreages. In order to use all the available land the number of farms in all groups will be divided by this percentage, such that exactly 100 percent of the available land is used when the calculations are completed.

3.8.4 Investments in livestock capacity

Another problem when using Markov models is to model the development within farms. A Markov model estimates the number of farms in each group, but doesn't say anything about the changes happening within the farms, e.g. investments in larger capacity for livestock. Therefore those investments have to be calculated separately. Since KRAM's time horizon is 10 years, they cannot be omitted.

Jacobsen (1994) was able to show that farmers tend to invest when the cash is available, where an economist would advise to invest when the investment is profitable. Given Jacobsen's analysis, it is expected that there is a strong correlation between farm profits and farm investments. Denmark's Statistics has data on investments in stables for pigs and cows. There are also data on farm profit and the total number of sows and cows. Furthermore, there has recently been a large export of piglets, which has to be taken into account.

Given these data, the following method will be used to estimate the number of sows per farm in the largest pig farm group (as for the areas of smaller farm groups, the average won't change over time). By an econometric analysis the aggregate number of sows per region is estimated[15]. The explaining variables will be past profit on pig farms, past profit on other farms, and private consumption on pig farms, all for each region[16]. This aggregate number of sows now has to be distributed. First all farm groups but the largest pig farm get their sows. From section 3.8.3, we know the number of farms in these groups. Therefore it is simple to calculate the aggregate sow inventory of these farms. Left over is a number of sows, and a number of farms in the largest pig farm group. These sows will simply be distributed to these farms.

Using the results on productivity from the technology submodel, the number of piglets produced is estimated. Some are exported, and that amount will be removed from the market. The rest of the piglets have to be distributed among farms with finishing capacity. The model will do this endogenously, generating an endogenous price on the piglets, and distributing the piglets according to available stable capacity and profitability on farms.

An estimate of piglet exports has to be calculated, but that will typically be part of the scenario analyzed. In a later version of the model, piglet exports may be derived endogenously. By using the method described here, it is assumed that there exists an (almost) perfect market for production of and trade with pigs. This assumption is not a problem for the Danish pork sector.

As for the number of cows, the problem is more complicated. This market is anything but perfect. Since 1984 the milk quota system has been used. Since then several different systems have been tried, in order to avoid freezing the structural development in the milk sector. Beginning in autumn 1998, a new milk exchange market will come into effect, and it is so far unknown what effect this will have on the distribution of milking cows. Therefore, this part of the model will await some results from the new milk exchange market before deciding on the method to model long-run structural development in the milking sector.

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[15] This will probably be done using the method proposed by Fabiosa and Qi (1998)

[16] The explicit choice of function etc. will be discussed in a forthcoming paper.

The main problem of this approach is that it has to be calibrated very carefully in order to give plausible results.

3.9 Technology submodel

As the model is proceeding from one time period to the next, the production technology needs to be changed. For accuracy, the aggregate technological change has to be divided in two parts: One is due to “real” technological change, where the input-output ratios actually change. The rest is due to structural development, where efficient farms buy inefficient ones, and when they impose their production method throughout the whole new farm, the average productivity is raised. Further theoretical description of technological change is in Wiborg and Rasmussen (1997; pp. 37-40).

In KRAM, the first type of technological change is treated in this submodel, and the latter in the structural submodel. Therefore, the factors desired are the rates of technological change within each farm type. These factors are estimated at DIAFE. In general, the input-output ratios are changed for each farm type, at the speed observed at this specific farm type in the past. Should there be reason to expect a different development, then it is used.

3.10 Prices submodel

As described earlier, KRAM works with two price sets: One is the set of expected prices, used for planning production, and the other is the set of final realized prices, used for calculating profit. The reason for working with two different sets of prices is to reflect the uncertainty in agricultural production. It takes a long time, in some cases more than a year, from the time the production decision is made until the goods are sold. In the meantime prices may change significantly. If the model allows farmers to have perfect foresight about prices, they will be able to plan production significantly better than in the real world. And since the purpose is to model the real world, and not to model a perfect world, this problem needs some attention.

In KRAM, an expected set of prices is calculated for each farm type, and when production has been carried out, the real price is determined. Therefore, this submodel is very closely linked to the market submodel. The expected prices for the next production year are calculated here. The market submodel calculates the realized prices.

Having established the need for calculating farmers' expected prices the question left is how to do it. In other words, given the information set Ω_{t-1}, how can the expected prices $E(P_t|\Omega_{t-1})$ be predicted? Throughout KRAM it is assumed that farmers are rational.[17] But how do rational farmers decide on expected prices, based on limited information? In the literature, there are several proposals. Researchers generally agree that the most efficient way to predict prices is to use futures prices (Gardner, 1976; Choi and Helmberger, 1993; Sulewski *et al.*, 1994).

Sulewski *et al.* (1994) tests a naive, a first-order autoregressive, a moving average (n = 2,3,4), a Turnovsky's extrapolative, a Nerlove's adaptive, and a Nerlove's quasi-rational expectations model. Their results are displayed in Table 3.1, where a lower score indicates better performance in estimating farmers' price expectations.

Table 3.1. Testing different expectation hypotheses.

	Average squared errors for wheat	Average squared errors for canola
Initial price	26.38	30.03
First-order autoregressive	**21.70**	29.92
Moving average (2 years)	**21.88**	**28.72**
Moving average (3 years)	25.78	31.62
Moving average (4 years)	28.46	34.98
Turnovsky's extrapolative	28.41	29.77
Nerlove's adaptive	29.32	31.36
Nerlove's quasi-rational	27.65	32.23
U.S. futures	34.15	43.82

Source: Sulewski *et al.* (1994).

[17] Rational in the sense proposed by Muth (1961), meaning that farmers may not be correct in their price predictions, or even agree, but they use the information set available to them to make the best possible prediction.

The study concludes that U.S. futures predict prices better than any expectations model. However, it is obvious from the results that even though futures prices do well in predicting prices, they do extremely poorly in predicting farmers' price forecasts. That eliminates the use of futures prices in this analysis as an explaining variable of farmers' price forecasts. The best model for explaining farmers' predictions appears to be a moving average with $n = 2$, as shown in equation 3.4, where i is the good number, t the time period, P^e the expected price, P the realized price, and α and β are parameters.

3.4 $$\mathrm{E}\left(P_{i,t} \middle| \Omega_{t-1}\right) = \alpha_i + \beta_i \left(\frac{P_{i,t-1} + P_{i,t-2}}{2}\right), \text{for } \forall i .$$

Fisher and Tanner (1978) conducted a similar study with Australian farmers, and found that an adaptive expectations model (equation 3.5) is the best description of farmers' price expectations.

3.5 $$\mathrm{E}\left(P_{i,t} \middle| \Omega_{t-1}\right) = \mathrm{E}\left(P_{i,t-1} \middle| \Omega_{t-2}\right) + \left(1 - \alpha_i\right)\left(P_{i,t-1} - P^{e}_{i,t-1}\right), \text{for } \forall i .$$

The question is now which model to choose. The deciding factor will be the setup of the different studies. In the case of the Sulewski *et al.* (1994) analysis, a total of 770 predictions of wheat prices and 427 predictions of canola prices were made at "Top Management Workshops" from 1987 to 1992. The guesses were only on next year's price, not farther into the future. The purpose of the predictions was to use detailed computer models to compute the individual participant's cost of production, compute financial performance, and conduct long-run financial planning. Farmers were asked to give their best guess of the price of goods they knew well, depended on, and had been working with for years.

The Fisher and Tanner (1978) data were collected in this way. A representative sample of 55 farmers was given 10-year prices for an agricultural good (they didn't know which), and they were then asked to predict the prices for the next three years. They got no more information than that. Even though the good in question actually was an agricultural good (potatoes), there was no possibility they could use their professional knowledge.

It is obvious that the two studies' data are very different. The Sulewski *et al.* (1994) study uses data collected from farmers who rely on their professional knowledge. Fisher and Tanner's study looks more like a theoretical study of how people in general react to a list of numbers, not how professional farmers predict prices, using all available information and experience. Therefore, KRAM will use the Sulewski *et al.* recommendation to use a moving average model to predict farmers' price expectations. The selection method used here is supported by the discussions in Irwin and Thraen (1994; p. 148) and in Keane and Runkle (1990).

Finally, government market intervention has a major influence on both prices and price expectations (Chavas *et al.*, 1983; Orazem and Miranowski, 1994). Therefore, the price expectations have to reflect expected government market intervention. The formula has to include a G_t, where G_t is a measure of the expected government influence on price in period t (3.6). Hereby the farmer's price predictions for each good are effectively made up of two disjointed parts, namely a moving average of prices and a variable reflecting governmental influence.

3.6
$$\mathrm{E}\left(P_{i,t} \middle| \Omega_{t-1}\right) = \alpha_i + \beta_i \left(\frac{\left(P_{i,t-1} - G_{i,t-1}\right) - \left(P_{i,t-2} - G_{i,t-2}\right)}{2} \right) + G_{i,t} \,.$$

A priori, there is good reason for prices to be different for different farm types since there can be differences in product quality and homogeneity from different farm types, and since the farmer may encounter economies of size when trading. Prices are usually expected to be better for farms with a large trade volume, and a good financial state, since they pose a smaller risk and smaller costs to their trading partners. Therefore KRAM must also be able to differentiate prices for different farm types.

Furthermore, it is probably true that full-time farmers have more insight into recent developments, and therefore are better at guessing the price next year than part-time farmers. At least it is definitely true that the bigger farms have more to gain from knowing the right price, than the smaller has (Tada, 1991; p. 64). Evidence and a measure of the magnitude is lacking for these statements, so it is assumed that both smaller and larger farmers are equally skilled at forming expectations.

Note that even though all farmers' price prediction skills are equal, there will still be a price differentiation between farm types due to economies of size in trading. Therefore, the final model will look like (3.7), where *j* is an index of farm types and F_{ij} is a correction for price differentiation, which is not dependent on the time period.

3.7: $$\mathrm{E}\left(P_{i,j,t} \middle| \Omega_{t-1}\right) = \alpha_i + \beta_i \left(\frac{\left(P_{i,t-1} - G_{i,t-1}\right) - \left(P_{i,t-2} - G_{i,t-2}\right)}{2} \right) + G_{i,t} + F_{i,j} \,.$$

The estimation of $G_{i,t}$ is based on the scenario analyzed. Later analysis will determine α_i and β_i.

3.11 Presentations

On the right-hand side of Figure 3.1, a number of presentations are sketched. These are all small programs, collecting data from the relevant submodels, and presenting them in a more comprehensive way. The idea is that one doesn't need to be an expert in reading computer printouts in order to use KRAM. These presentations should improve the usefulness for students, fellow researchers, and others interested in using KRAM without having to learn all about programming it.

4 Conclusion

The proposed model of the agricultural sector in Denmark is a spatial, dynamic, nonlinear, programming, sector model, with some econometric submodels. The model is capable of optimizing the production on farms disaggregated to a number of geographical regions and different farm groups in each region. The regions have homogeneous soil types, and since the farms are divided according to economic size and main source of income the model is well suited for analysis of externalities. The endogenous modeling of the use of fertilizer, manure, and pesticides further enhances this.

The model is dynamic, with a time horizon of 10 years. The structural development in agriculture is estimated endogenously, assuming that a Markov chain model can project the structural development in a base run, and that changes in farm types' relative profit from the base run are correlated positively with the number of farms in the same group. This approach is new, since estimates of structural development are usually carried out in separate or at least exogenous analysis. Calculating the structural development endogenously should improve the knowledge of different scenarios' effect on structural development.

Since real world farmers have to make decisions based on predicted prices, the same method is applied here. Several different functions for estimating farmers' price predictions are discussed, and a moving average of the two preceding years' prices selected. The function also includes expected policy actions. Demand for agricultural products is specified as farm gate prices, but the model is capable of using (nonlinear) demand functions. Most prices are exogenous to the model, but some intermediate goods and final organic goods have endogenous prices.

The development of the model is far from finished. Further analysis is needed to establish the demand for organic products, to predict the number of livestock over time, and to calibrate the structural and price expectations parts, just to name a few. When the model is finished it should become a valuable tool, both in terms of making what-if analysis, and in its theoretical value. In relation to existing models it is expected that this model should be well suited to analyze structural development, environmental effects of agricultural production, and regional differences. It will be relatively worse off if long-run equilibrium analysis is needed.

The main use of this paper is naturally to form the theoretical basis for the empirical work ahead. But the structural submodel may also be used as a general proposal to similar models. Since the approach is new, it may help others to invent better ways to estimate the structural development.

The further work on KRAM can be followed in a series of forthcoming papers from KVL.

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