The Royal Veterinary and Agricultural University
Food and Resource Economic Institute

KVL | A UNIVERSITY OF LIFE SCIENCES

Unit of Economics Working Papers 2000/2

A Comparison of Agricultural Sector Models: CRAM, DRAM, SASM and the KVL Model.

Torben Wiborg

2000/2 A Comparison of Agricultural Sector Models: CRAM, DRAM, SASM and the KVL Model, *by Torben Wiborg.*

1 Summary

Four different programming models dealing with the agricultural sectors in Canada, The Netherlands, Sweden and Denmark are analysed. The purpose is to construct a knowledge base for the development of a new sector model for Danish agriculture. This analysis has created a valuable set of resources for use in the development of the model.

2 Sammendrag

Fire forskellige programmeringsmodeller omhandlende landbrugssektorerne i hhv. Canada, Holland, Sverige og Danmark er analyseret, med henblik på at opnå en basis for udviklingen af en sektor model af den danske landbrugssektor. Hovedkonklusionen er, at en værdifuld samling af værktøjer og metoder er tilvejebragt, som kan bidrage under modeludviklingen.

3 Introduction

This paper analyses four different agricultural sector models. The main purpose is to establish a knowledge base, which can be used to construct the sector model for Danish agriculture KRAM (KVL's Regional Agricultural Model). KRAM is described in Wiborg (1998), Asmild and Wiborg (1999), Wiborg (1999), Wiborg and Rasmussen (2000a) and Wiborg et al. (2000b). The models discussed are programming models, which analyse problems similar to those that we intend to analyse with the new Danish sector model. Consequently, it is relevant to investigate these models in detail before investing time in constructing the Danish model.

This paper was written in the autumn of 1998. The present version includes revisions made during the spring of 2000.

The four models chosen for the study have been selected on the basis of a literature survey. They all contain a comprehensive description of the agricultural sector, and are all programming models. Furthermore, each of these four models have implemented some very interesting modelling techniques, which are evaluated in order to search for relevant tools for KRAM.

The first model analysed is CRAM (Horner et al., 1992), which describes the Canadian agricultural sector. This model includes transport costs and export of agricultural goods as important elements. The version analysed in this paper dates from 1992, since this is the version which has the fullest documentation available. Newer versions have appeared since then, but they are only documented in short papers, each describing the advances from the previous to the current version, and lacking a good overview of the whole model.

The next model investigated is the Dutch DRAM model (Helming, 1997). This model focuses on agricultural production and its environmental effects. The aggregate environmental impact and the factors in primary agriculture with an environmental effect are described in great detail in DRAM. Since analysis of environmental problems related to Danish agriculture is among the most important reasons for constructing a new sector model, the DRAM model is very interesting.

The Swedish SASM model (Apland and Jonasson, 1992) is especially interesting for its choice of calibration method. Most modern European programming sector models are calibrated using Positive Mathematical Programming (PMP, Howitt (1995). SASM introduces a methodological discussion on the validity of the PMP calibration technique, and is hence calibrated with another technique.

Finally, the Danish KVL model (Andersen et al., 1974) is analysed. This model is included because of the numerous interesting ideas presented, and because it describes the *Danish* agricultural sector. A number of specific Danish problems have been considered, which are important for KRAM.

Central features for each model have been selected in order to compare the models. However, the focus remains on the factors specifically relevant for the Danish sector model. This naturally implies that not every aspect of each model is covered. These sections cover:

1. **Overall modelling methodology**. Which optimisation criterion is used? Do farmers use price expectations, and if so, how are they estimated? Are prices endogenous or exogenous, and which goods are traded endogenously in the model? How is consumer demand considered? Are transport costs included? How is the crop mix calibrated?
2. **Aggregation method and level**. How are the data aggregated from local (to regional) to national level? Are representative farms or aggregated supply functions used?
3. **Goods**. Which crop and livestock types are included in the model?
4. **Restrictions**. Which types of restrictions are applied in the model?
5. **Dynamics**. How are investments and the dynamic development over time considered?

4 CRAM

The first version of the Canadian Regional Agricultural Model (CRAM) was developed at the University of British Columbia in 1986 (Webber et al., 1986). Later, Agriculture Canada improved CRAM in cooperation with Iowa State University and U.C. Davis (Horner et al., 1992). The model analysed here is the 1992 version. The model has been described further in later papers, e.g. Bouzaher *et al.* (1995). These papers are not used in this discussion, since they do not give a complete documentation for CRAM but describe smaller developments within the model.

4.1 Overall modelling methodology

CRAM is a combination of an econometric sector model and a programming sector model. The agricultural production in each region is optimised in a non-linear programming (NLP) problem. The optimisation criterion is maximisation of the Marshallian surplus (consumer plus producer surplus) less processing and transport costs.

Livestock production is optimised over several periods, and most crop and livestock production costs are specified using Leontief production functions. The supply of crops and livestock is determined in an econometric manner, using assumed supply elasticities and demand functions. The crop distribution is calibrated using PMP. CRAM uses some elements from programming as well as econometric models, and attempts to exploit the benefits of both approaches, while at the same time avoiding the drawbacks. Bauer (1989) discusses the benefits of combining these model types, and concludes that there are major advantages by doing so.

The model contains five spatial levels: national, east and west, provincial, crop regions and shipping ports. The crop regions are located on the prairies, and are primarily differentiated by soil types and climatic zones. There are 29 different crop regions.

The “national” and “east and west” levels are demand regions. Goods have to be transported from the production regions. Wheat, barley, beef, pork, milk products, chicken, eggs, turkeys and other crops are purchased at the “east and west” level, while canola, soybeans, veal and other dairy products are purchased at the “national” level.

This approach allows the consumer price to vary between eastern and western Canada, where the maximum price difference is the transport costs between the regions. It also creates a flexible model with endogenous prices. The possibilities for export and import impose a floor and a roof to the possible consumer prices in Canada as illustrated in Figure 1. (In Figure 1, P is domestic price and Q domestic production.) If domestic prices get too low, farmers will export, and if they get too high consumers will import. In fact it is not the whole demand curve, which is estimated, but rather the current consumption and price level and the elasticity.

Certain minimum levels of exports and imports are set exogenously. The small country assumption is maintained for all goods, meaning that export and import prices are constant.

There are no price expectations in the model; supply is determined solely by the realised price, the PMP functions (for crops) and supply elasticities (for livestock).

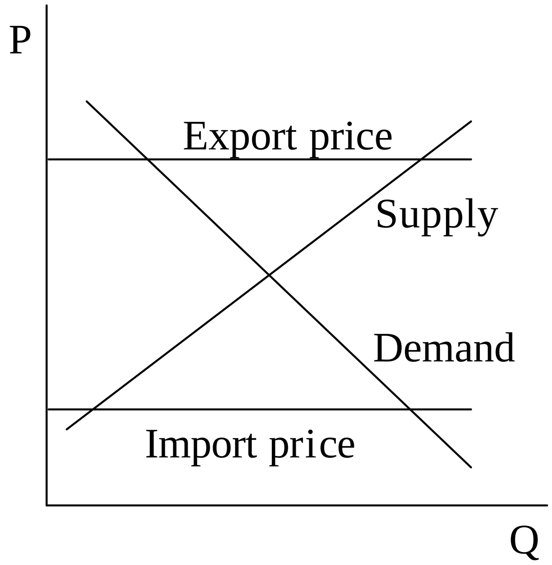

Figure 1: Price generation in CRAM

4.2 Aggregation

The agricultural production in a region is a function of the aggregated production resources and constraints. CRAM is not based on representative farm types. This makes CRAM a smaller model in terms of the number of equations. Analysis of environmental impact is difficult in this sort of model. On the other hand, it may be well suited to analysing the effects of price changes and scenarios containing policies that have similar impact on different farm types.

4.3 Goods

12 different crops are considered in CRAM, these being four grades of wheat, barley (including other coarse grains), flax, canola, corn, soybeans, hay, pasture and other crops. All crops except the last three are calibrated using PMP. The livestock products beef, pork, dairy, broilers, eggs and turkeys are considered.

4.4 Restrictions

Some equilibrium constraints are naturally needed for a model with endogenous trade between producing and consuming regions. There are no restrictions on crop rotation, since the areas used for crops are either a direct function of the need for feed for livestock or estimated using PMP. The model has restrictions on available land, but only one restriction for each region, since no farm types are present. Furthermore, no trade between different farm types is modelled.

4.5 Dynamics

In order to capture the investments and disinvestments in the beef, dairy, poultry and hog sectors, so-called retention functions are used. A retention function is a flexibility constraint, which is limiting the processes, and thereby calibrates the model.

The solution of a retention function is the opening stocks at time t+1. The arguments for a given retention function are the current price of the good (P_t), the expected price of the good (P_{t+1}^e) and the elasticity of stocks with respect to price (own price or price of an input). Prices and expected prices of relevant inputs may also be used. Finally, a range parameter is included in order to ensure that changes are within a reasonable range, even if major price changes occur.

Different retention functions are defined for each animal type and province. Retention functions are not used in the crop part of CRAM. They can be activated or deactivated as desired, according to the duration of the current scenario (long run or short run).

The estimation of agricultural investments has a medium or long run perspective, depending on the range parameters. It is quite similar to a CGE approach, where elasticities determine supply and demand. The path taken towards the equilibrium is not estimated.

4.6 Resume

CRAM is a good example of a model focusing very much on the transport of goods, and using endogenous prices. It uses PMP to calibrate the crop mix. The model will probably encounter some difficulties when farmtype specific policies are analysed, due to its regional construction without representative farm types. However, in the light of the differences between Danish and Canadian agricultural policies, this model is probably modelling the Canadian agriculture at least as good as a model with representative farms. Furthermore, the data requirements for this model are significantly smaller. This technique does not capture sufficient detail to model the current Danish agricultural and environmental policies.

5 DRAM

The Dutch Regionalized Agricultural Model (DRAM) is described in Helming (1997). A more recent version of DRAM has been published since then (Helming et al., 2000), but the present description is based on the 1997 version. The first version of DRAM was developed in 1986 (Bakker, 1986).

The 1997 version of DRAM can be described as a regional, multisectoral, mathematical programming, comparative static, spatial equilibrium model, with special emphasis on environmental variables.

Among other things, DRAM has been used to investigate the long-term impacts of the MacSharry reform on the economy and the environment in the Netherlands.

5.1 Overall modelling methodology

The optimisation criterion is the national profit from agricultural production less transport costs, under the restrictions that demand equals supply in all regions. Production is generally modelled using Leontief production functions and linear programming (LP), but since PMP is used to calibrate DRAM the overall model is non-linear.

DRAM applies PMP to calibrate both production of cash crops, roughage crops and the intensive livestock production. Calibration of livestock using PMP has only been done in few other models, for example Bauer and Kasnakoglu (1990).

Transport of both final goods and intermediates between regions and internationally is possible, and transport prices are applied. Unlike the Canadian model, DRAM does not require that a specific export port has to be reached before goods can be exported. However, the goods have to be transported to the nearest point on the border. Consequently, different transport prices for exports for each region have been introduced, as well as different transport prices to different domestic regions.

The option of trading internationally with intermediate goods is not present in any of the other models investigated in this paper, but it can be defended on two grounds. Firstly, since distances to other countries are relatively short for Dutch producers international trade even with intermediates is possible. Secondly, the EU internal market reduces the possibilities for other countries to restrict such trade. One interesting difference from most other models implied by this is that international trade in manure is possible. Trade in piglets and suckler calves is also carried out, which is more relevant to a Danish model.

All prices are exogenously fixed farm gate prices, and expected prices are not used in DRAM.

5.2 Aggregation

DRAM has fourteen regions, each having one of three different soil types. Each region is treated like one large mixed farm. With this approach the model has a large degree of regional and physical specificity. However, some aspects of farmers' adaptation processes are lost in comparison to a farm-based model.

On the environmental side the model is very disaggregated. Among the environmentally relevant variables are the emission of ammonia from stables, pasturing and application of manure, surplus of minerals in the soil and the use of pesticides disaggregated on fungicides, herbicides, insecticides, nematicides and others. The excretion of nitrogen and phosphorus per dairy cow is a function of milk production per cow, feeding rations and mineral application on grassland. The national use of pesticides is a function of land use and regions.

Livestock production is described in great detail in DRAM. The model separates different stages of cattle production (fattening, reproduction, milking cows, fattening bulls, heifers etc.) Several feeding regimes are considered endogenously in the model; for instance, milking cows have seven different feeding rations that are freely chosen by the model.

5.3 Goods

In the arable sector, eleven marketable outputs are identified. These are cereals, pulses, sugar beets, ware potatoes, seed potatoes, starch potatoes, onions, other arable products, flower bulbs and two types of vegetables grown in the open. In addition grass, silage and fodder maize are produced as roughage.

Livestock products are separated in a cattle farming sector (milk and beef originating from milking cows and grazing livestock including bulls, heifers, and suckler cows) and in an intensive livestock sector (pork, poultry meat, eggs, piglets, pigs and day-old chickens.)

5.4 Restrictions

Regional equilibrium restrictions are applied for all marketable goods. Milk and sugar quotas restrict production. The milk quota can be traded between regions, while the sugar quota is imposed on the regional level. A regional manure quota is applied, but this quota can be traded between different manure types in the intensive livestock sector. The manure quotas are based on actual manure production in the manure surplus regions and on the ratio of land to manure production in the manure deficit areas.

In order to calibrate the PMP used in the livestock and arable sectors, an initial model run is restricted by actual observed levels of crop acreage and livestock stocks. These restrictions are then replaced by the PMP costs in the object function before using the model. In addition to these restrictions, a number of policy restrictions are applied.

5.5 Dynamics

DRAM is a comparative static model. The solution can be interpreted as a long-term equilibrium. The model solution provides the optimal annual profit and production of agricultural goods. Investments are considered endogenously, for example milk quotas may be traded freely.

5.6 Resume

The DRAM model has a lot of interesting features related to the environmental variables. Since the environmental debate in Denmark and The Netherlands proceeds along similar lines, many of the environmental considerations in DRAM are relevant in Denmark. The model proves that it is possible to include an extremely detailed description of pesticide application, manure application and trade, while it still is solvable. PMP is used extensively, and apparently with good results. It is also interesting to see how the cattle sector has been highly disaggregated.

6 SASM

Jeffrey Apland (University of Minnesota) and Lars Jonasson (Swedish University of Agricultural Sciences) constructed the Swedish Agricultural Sector Model (SASM). The model is described in Apland *et al.* (1994) and Apland and Jonasson (1992). It describes the demand of the Swedish agricultural sector and Swedish consumers for agricultural goods and intermediates, and includes international trade. This description of SASM focuses on the SASM-D1 version, since this version has the best documentation.

A single comment on an interesting development in a later version of SASM is relevant here. Jonasson and Apland (1997) implements distance functions in order to create farm types. This approach assumes that small farms are less efficient than larger farms. Only a single farm of each type (i.e. pork, dairy, arable) needs to be identified, and the others are considered to be either more or less efficient versions of this farm. This approach allows technological development over time to be a function of the relative efficiency as well as the improved efficiency on the most efficient farm type. It also significantly reduces the amount of data needed.

6.1 Overall modelling methodology

The optimisation criterion in SASM is the Marshallian surplus less transport costs. The model is solved on an annual basis. Supply is modelled using normal Leontief production functions. In both the CRAM and the DRAM models, PMP was used extensively. In SASM this approach is not applied, due to the lack of an empirical basis for the construction of implicit cost functions. Since this calibration strategy deviates from the PMP approach used in CRAM and DRAM, and since this is a very important issue for the KRAM model, it seems worthwhile investigating this subject further. The subject is taken up in McCarl, Rasmussen and Wiborg (2000).

SASM uses production processes where multiple products are produced. For example a number of different processes describe the production possibilities and costs per 1000 ha. One process produces wheat on 200 ha, barley on 600 ha and rapeseed on 200 ha. The output is the tonnes of goods produced considering the expected yield of this crop mix, while the cost of the process is the production costs by producing these goods. An alternative process may contain the yields and costs of producing wheat on 600 ha, barley on 200 ha and peas on the last 200 ha. By choosing between this type of processes as opposed to processes producing a single crop, extreme specialisation is avoided (Apland and Jonasson, 1992; p.p. 17-20).

Demand is specified as regional demand functions, and trade between regions is possible. Therefore, prices become endogenous in SASM. However, import and export prices are constant and defined exogenously, applying the small country assumption.

6.2 Aggregation

The spatial structure of SASM has three levels: subregions, regions and national. There are five regions, and they contain a total of twelve subregions. All goods may be transported between subregions and regions, and final goods can be sold from regions to the national level. Transport costs are calculated using the unit transportation cost per 1,000 km.[1]

The subregions are mainly used for disaggregating production activities into homogeneous areas. Another use of the subregions is to integrate crop and livestock production activities associated with immobile items such as forage, permanent pasture and arable land. Farm production activities may also be regional. The version of SASM described here comprises only one large farm in each region.

An interesting feature in the SASM model is the inclusion of processing industries. Products such as cream and dry milk are produced at dairies with a fixed cost per unit (effectively a price margin). The goods sold to consumers are the final goods, and demand functions deal with final goods as opposed to the farm products.

6.3 Goods

Unlike the other models discussed, SASM does not consider the numbers of animals explicitly. SASM works with various inputs and outputs, as de-

[1] See Apland and Jonasson (1992) program lines 1182-00, 1359-61, 1469 and 1535.

scribed in the tables in Appendix 1. In total, 55 different inputs or outputs are identified.

6.4 Restrictions

Equilibrium restrictions ensure that all markets clear in SASM. Leontief production functions are applied, and often several different Leontief functions are specified for each product (as demonstrated in Figure 3.) The model does not include further crop rotation constraints than what is indirectly included by using multiple product processes.

6.5 Dynamics

SASM is a one-period model, but the solution is a long-term equilibrium. For example, some restrictions on dairy production imply the option of significant shifts in production levels – a solution that would be impossible to achieve within a single production year. Throughout the model the solution is normative rather than positive.

There is no explicit modelling of investments, but exogenous supply functions for dairy production facilities enable the model to increase the dairy production over time. There is no upper limit for the production of dairy products, while a supply limit for pork and poultry production is introduced.

The path taken to achieve equilibrium is not modelled in SASM. As a consequence of the long term planning horizon, expected prices are not implemented.

6.6 Resume

The SASM model is especially interesting because it raises a discussion about calibration techniques. While most other agricultural sector models use PMP, SASM does not due to methodological problems. Another interesting feature is the use of processing industries, which turns the raw agricultural products into final goods, for which the direct demand can be estimated from consumption data. However, this approach also increases the relevant number of goods dramatically.

The approach suggested by Jonasson and Apland (1997), to implement distance functions and efficiency analysis to create farm types, has been discussed in the KRAM project. It has been concluded that using this approach would be an oversimplification of the farming sector in Denmark. There are more differences between large and small farmers than their efficiency level. For example, larger farmers tend to invest a lot, while smaller (part time) farmers often keep the same size of the farm over time. Furthermore, large farms typically have completely different capital-labour ratios in the production, and are far more specialised than small farms. When constructing the model, the difficulties of getting data for further farm types are significantly less than for getting data for the first farm type. This means that the costs of using the distance functions in a sector model may exceed the benefits, at least in the case of Denmark, where farm data are relatively easy to access.

7 The KVL model

The KVL model is a joint name for a series of models developed at the Department of Economics at the Royal Veterinary and Agricultural University in Copenhagen (KVL). The first model is described in Andersen *et al.*, (1974). The most recent major revision of the model was undertaken in 1992 (Stryg et al., 1995). The model version from 1979 (Andersen et al., 1979) is the one described in this study. This was the most fully developed model in terms of endogenous simultaneous modelling of structural development, production economics and regional distribution.

7.1 Overall modelling methodology

The KVL model is an interregional recursive LP model, where the optimisation criterion is maximisation of the national gross margin. The model is regional in construction and has a number of representative farm types in each region. These farm types are formulated as LP models. Regional models are formulated as the totality of these farm firm LP models in addition to some regional restrictions. The regional restrictions are mainly on the available land and flexibility constraints in order to model structural development.

The regional models are connected to an interregional model (Figure 4) by applying some national restrictions. These national constraints mainly ensure equilibrium in the endogenous markets for trade in piglets and suckler calves. The small country assumption has been applied to the KVL model.

The purpose of the KVL model has mainly been policy analysis, but various analyses of machinery investments have also been undertaken. The model was reformulated and updated several times throughout the 1980s.

Region 1		Region 2				
Gr. 1	Gr. 2	Gr. 1	Gr. 2			
X^{11}	X^{12}	X^{21}	X^{22}	Variables		
C^{11}	C^{12}	C^{21}	C^{22}	Object function		
A^{11}				$\leq$	B^{11}	Farm group restrictions
	A^{12}			$\leq$	B^{12}	
		A^{21}		$\leq$	B^{21}	
			A^{22}	$\leq$	B^{22}	
D^{11}	D^{12}			$\leq$	DD^{1}	Regional restrictions
		D^{21}	D^{22}	$\leq$	DD^{2}	
E^{11}	E^{12}	E^{21}	E^{22}	$\leq$	EE	National restrictions

Figure 4: The KVL model structure. Source: Andersen et al. (1974).

In Figure 4 X is the variables, C the values in the object function, B the group restrictions (flexibility constraints, resources), DD regional restrictions, EE national restrictions, A the technical coefficient matrices (need for feed, yields, use of labour etc.), D the regional matrices and E the national matrices.

7.2 Aggregation

The model has eleven production regions and four representative farm types within each region. These farm types are classified by acreage. This classification was reasonable when the model was developed, given the homogeneity of farms. Most farms had several different types of livestock, and had more or less similar distributions of crops, at least within each region. Hence, there was no need to differentiate farm types further. Given the very specialised farms in modern agriculture, it is necessary to distinguish between main product to achieve homogeneous groups.

The production regions are aggregated to three trade regions, which in very general terms are east, central and west Denmark. The trade regions are also considered to constitute consumption regions, and export is possible from ports in each of the three regions. This, together with the fact that Denmark is a relatively small country in geographical terms, means that it is reasonable to assume identical transport costs for each farm regardless its geographical location.

Consumption is assumed to be perfectly elastic, i.e. output prices are fixed at their expected farm gate values.

7.3 Goods

The KVL model considers winter and spring wheat, winter and spring rye, spring barley, oats, potatoes, sugar beets for industry, fodder beets, grass in rotation, grass not in rotation, catch crops and other crops (an aggregate).

Furthermore, the following livestock types are considered: cows (including young stock), steers, bulls and other beef cattle, sows (including piglets), porkers, hens, slaughter chickens and other poultry, horses and sheep.

7.4 Restrictions

In the KVL model, the PMP technique is not used (PMP was first introduced several years after the model was developed). Since the SASM approach is not applied either, another type of restrictions on crop distribution is needed to calibrate the model. The KVL model is calibrated by flexibility constraints that form upper and lower bounds on the change in acreage for each crop from one period to the next. The same method is applied for livestock production. There are some exceptions to this. Spring barley has only an upper limit, and for potatoes, sugar beets, other crops, hens, slaughter chickens and other poultry, horses and sheep the upper and lower limits are identical, and thus the levels of these processes are predetermined exogenously.

The flexibility constraints are set above and below *the expected production level* in the current period. This level is predetermined using an econometric function in the optimal level in the previous period, the shadow prices on these restrictions in the previous period and some econometrically estimated parameters, which are exogenous to the optimisation model.

The production of roughage feed has to be in balance for each farm type. Cereals, suckler calves and piglets are traded, but the trade has to be in equilibrium within each of the three trade regions.

7.5 Dynamics

The periods in the KVL model have a duration of three years. The model was originally calibrated on the basis of six periods (i.e. eighteen years) and estimated for the following five periods. The estimation of structural development is especially interesting in this model. Flexibility constraints limit the number of farms in each group and region from above and below, and with the inclusion of a constraint on available land in each region, the number of farms becomes endogenously determined. The shadow prices on the flexibility constraints determine the flexibility constraints in the next period.

These flexibility constraints ensure that the estimate of structural development becomes an indirect function of the relative gross margin for the farm types. In other words, the relative pressure on the flexibility constraints co-determines how they are placed in the next period (Andersen, 1976).

In order to model the change in herd a multi-year model was formulated for cattle. For pigs and young bulls only a single-year model is needed. The changes in livestock stocks are estimated using two processes for increases and two for decreases in stocks for each animal type.

The KVL model clearly analyses both a medium and a long-term perspective where the model tends to move towards equilibrium. A series of optimal points at different times are given as the solution. But the solution in the last period is not the final equilibrium, but rather represents the amount the agricultural sector has moved during the time period in question. Expected prices are not used in the KVL model.

The KVL model is especially interesting due to the detailed description of the development in the herd over time. Such a structure is essential when the periods in the model are shorter than the time necessary to increase the herd. The long calibration period is also interesting. This approach ensures that the model has a strong link to the previous development in the sector. The use of representative farm types appears to give a very strong model in terms of ability to demonstrate different problems at different farm types, which might otherwise disappear in the aggregation. However, the farm types in the KVL model only differ in their acreage. This would not be sufficient in modern agriculture, where farms are highly specialised. Finally, the recursive construction is appealing, and seems to provide a convincing picture of farms' development over time.

8 Conclusion

The four models analysed have many similarities. They all deal comprehensively with the agricultural sector, covering just about every important factor for agriculture in the countries in question. All the models are optimisation models handling interregional trade in agricultural products and intermediates.

However, the models also have significant methodological differences, mostly based on the varying political realities. It is no coincidence that the Canadian model focuses mainly on trade routes and exports, whereas the Dutch model looks primarily into environmental problems. These selections of main fields of interest closely mirror the *de facto* production limitations and current political interests in the respective countries.

All the models estimate the long-term equilibrium. But only the KVL model shows the path taken towards this equilibrium. CRAM, DRAM and SASM provide the equilibrium, and do not consider how to get there. None of the models use expected prices. This suggests that the solutions are either considered as Nash equilibriums, or alternatively that farmers are risk neutral and have perfect information.

There is also an important difference in the calibration techniques used. PMP is used in DRAM and CRAM, but not in SASM. This difference is interesting, since the SASM programmers could actually have used PMP, but decided not to because of methodological problems.

Only the KVL model differentiates between farm types. This approach is more data demanding, but it also facilitates detailed analysis in factors that affect different farm types in different ways.

The three foreign models all consider the transportation costs of domestic and international trade. The Danish model does not, but this may very well be an effect of the relatively small size of Denmark. It is obvious that a Canadian or Swedish model needs to incorporate transportation costs in a more detailed manner than a Danish model, due to the distances in the these countries.

The models analysed have used several different modelling techniques and methodologies, and the overview of these will serve as an important tool box when constructing KRAM.

9 References

Andersen, F. (1976) *Rekursive LP-modeller med variable fleksibilitets-grænser (Recursive LP-models with variable flexibility restrictions).* Copenhagen: The Royal Veterinary and Agricultural University, Department of Economics.

Andersen, F., H.P. Hansen, P. Pilgaard, and P.E. Stryg (1974) *Dansk Landbrug i 1985? Prognose over den danske landbrugsproduktions størrelse, regionale fordeling og struktur frem til 1985 (Danish agriculture in 1985. Prognosis for the size, regional distribution and structure of Danish agricultural production until 1985).* Copenhagen: Department of Economics, KVL.

Andersen, F., S. Rasmussen, and P. E. Stryg (1979) *Dansk landbrugs regionale udvikling frem til 1990 (The regional development of Danish agriculture until 1990).* Landbrugsøkonomiske studier 12. Department of Economics, KVL, Copenhagen.

Apland, J. and L. Jonasson (1992) *The Conceptual Background and Structure of SASM: A Swedish Agricultural Sector Model.* Report 45. Swedish University of Agricultural Sciences, Department of Economics, Uppsala.

Apland, J., B. Öhlmér, and L. Jonasson (1994) *Economic Analysis of Agricultural technologies and Policies - The Sector Modelling Approach.* 71. SLU Info/Repro, Uppsala.

Asmild, M. and T. Wiborg (1999) *A relatively easy-access description of the logistics, purposes and function of the sector model KRAM.* Unit of Economics Working Paper 1999/3. Department of Economics and Natural Resources, Unit of Economics, KVL, Copenhagen.

Bakker, Th. (1986) *Staging Agriculture. Building and playing with a model of Dutch Agriculture.* Publication 1.19.The Hague.

Bauer, S. (1989) "Some lessons from the dynamic analysis and prognosis system (DAPS)." In *Agricultural Sector Modelling*. Edited by Bauer, S. and W. Henrichsmeyer. Kiel: Wissenschaftverlag Vauk, p. 325-344.

Bauer, S. and H. Kasnakoglu (1990) Non-linear programming models for sector and policy analysis. Experiences with the Turkish agricultural sector model. *Economic Modelling* July 1990:275-289.

Bouzaher, A., J. F. Shogren, D. Holtkamp, P. Gassman, D. Archer, P. Laskshminarayan, A. Carriquiry, R. Reese, D. Kakani, W. F. Furtan, R. C. Izaurralde, and J. Kiniry (1995) *Agricultural Policies and Soil Degradation in Western Canada: An Agro-Ecological Economic Assessment (Report 5: Project Summary).* Technical Report 2/95. Agriculture and Agri-Food Canada, Ottawa.

Helming, J. F. M. (1997) Agriculture and environment after CAP reform in the Netherlands; an application of an agri-environmental sector model. *Tijdschrift voor Sociaalwetenschappelijk Onderzoek van de Landbouw* 4:334-356.

Helming, J. F. M., L. Peeters, and P. J. J. Veenendaal (2000) "Assessing the consequences of environmental policy scenarios in Flemish agriculture." *Agricultural Policy Information Systems, Proceedings of the 65th EAAE Seminar, March 29-31, 2000 in Bonn* Vauk Verlag (forthcoming). Kiel.

Horner, G. L., J. Cormann, R. E. Howitt, C. A. Carter, and R. J. MacGregor (1992) *The Canadian Regional Agricultural Model, Structure, Operation and Development.* Technical Report 1/92. Agriculture Canada, Policy Branch, Ottawa, Ontario.

Howitt, R. E. (1995) Positive mathematical programming. *American Journal of Agricultural Economics* 2. 77:329-342.

Jonasson, L. and J. Apland (1997) Frontier technology and inefficiencies in programming sector models: An application to Swedish agriculture. *European Review of Agricultural Economics* 24:109-131.

McCarl, B. A., S. Rasmussen, and T. Wiborg (2000) *Setting up Sectoral Programming Models: A Review of Alternative Procedures for Aggregation and Calibration with Application to a Danish Sector Model*. Department of Economics and Natural Resources, KVL. *(Unpublished)*

Stryg, P. E., M. H. Knudsen, N. P. Ravnsborg, and F. Andersen (1995) *En interregional model for landbrugssektoren med modelberegninger frem til år 2000.* Social Science Series 4. The Royal Veterinary and Agricultural University, Copenhagen.

Webber, C.A., J.D. Graham, and K.K. Klein (1986) *The Structure of CRAM: A Canadian Regional Agricultural Model.* Vancouver: University of British Columbia, Department of Agricultural Economics.

Wiborg, T. (1998) *KRAM - A Sector Model of Danish Agriculture, Background and Framework Development.* Working paper 98-WP 193. CARD, Iowa State University, Ames, Iowa.

-----(1999) "KRAM - a Dynamic Programming Model Describing the Danish Agricultural Sector." *Nordisk Jordbrugsforskning 3.99:* 496-505. Nordic Association of Agricultural Scientists. Frederiksberg.

Wiborg, T. and S. Rasmussen (2000a) "Dynamic agricultural and environmental policy analysis using KRAM, a sector model of Danish agriculture." *Agricultural Policy Information Systems, Proceedings* *of the 65th EAAE Seminar, March 29-31, 2000 in Bonn* Vauk Verlag (forthcoming). Kiel.

Wiborg, T., S. Rasmussen, and J. M. Bramsen (2000b) *Modelbeskrivelse og dokumentation af data i KRAM (Model description and documentation of data in KRAM).* Social Science Series 7. Department of Economics and Natural Resources, Unit of Economics, KVL, Copenhagen.

10 Appendix 1

Input	Level of Spatial Aggregation	Exogenous Supply Function	Fixed Supply	Endogenous Supply	Inter-regional Transport
Arable land	Subregional	No	Yes	No	NA
Permanent pasture	Subregional	No	Yes	No	NA
Milk processing capacity	Regional	No	Yes	No	No
Cheese proc. capacity	Regional	No	Yes	No	No
Butter proc. capacity	Regional	No	Yes	No	No
Dry milk proc. capacity	Regional	No	Yes	No	No
Dairy facilities (farm)	Subregional	No	Yes	Yes	NA
Dairy facilities (remodelled)	Subregional	Yes	No	No	NA
Pig facilities	Regional	No	Yes	Yes	No
Poultry facilities	Regional	No	Yes	Yes	No
Poultry capacity	Regional	No	Yes	No	No
Labour	National	Yes	No	No	NA
Capital	National	Yes	No	No	NA
Energy	National	Yes	No	No	NA
Fertilizer	National	Yes	No	No	NA
Pesticides	National	Yes	No	No	NA
Other feed	National	Yes	No	No	NA
Other variable costs	National	Yes	No	No	NA
Miscellaneous costs	National	Yes	No	No	NA
Bread grain seed	Regional	No	No	Yes	Yes
Coarse grain feed	Regional	No	No	Yes	Yes
Dairy transfer payments B	National	No	Yes	Yes	NA
Dairy transfer payments R	National	No	No	Yes	NA
Dairy transfer payments C	National	No	No	Yes	NA

Table 1: Summary of inputs in SASM. Source: Apland and Jonasson (1992)

Product	Level of Spatial Aggregation	Exogenous Demand Function	Fixed Demand	Endogenous Demand	Inter-regional Transport	Export	Import
Bread grain	Regional	Yes	No	Yes	No	Yes	Yes
Coarse grain	Regional	No	No	Yes	No	Yes	Yes
Feed grain	Regional	No	No	Yes	Yes	No	No
Oil grain	Regional	No	No	Yes	Yes	Yes	No
Forage	Subregional	No	No	Yes	NA	No	No
Pasture grass	Subregional	No	No	Yes	NA	No	No
Other crops	National	Yes	No	No	NA	No	No
Milk (5 grades)	Regional	No	No	Yes	No	No	No
Milk subsidy	National	Yes	No	No	NA	No	No
Dairy bulls	Regional	No	No	Yes	No	No	No
Slaughter beef	National	No	No	Yes	NA	No	No
Slaughter pork	National	No	No	Yes	NA	No	No
Slaughter poultry	National	No	No	Yes	NA	No	No
Soybean meal	National	No	No	Yes	NA	No	Yes
Rape seed meal	National	No	No	Yes	NA	No	No
Skimmed milk	Regional	No	No	Yes	Yes	No	No
Milk fat	Regional	No	No	Yes	Yes	No	No
Consumption milk	Regional	Yes	No	No	Yes	No	No
Cheese	Regional	Yes	No	No	Yes	Yes	Yes
Butter	Regional	Yes	No	No	Yes	Yes	Yes
Cream	Regional	Yes	No	No	Yes	No	No
Dry milk	Regional	Yes	No	No	Yes	Yes	Yes
Oil	National	Yes	No	No	NA	Yes	No
Beef	National	Yes	No	No	NA	Yes	Yes
Pork	National	Yes	No	No	NA	Yes	Yes
Poultry meat	National	Yes	No	No	NA	Yes	Yes
Miscellaneous receipts	National	Yes	No	No	NA	No	No

Table 2: Summary of products in SASM. Source: Apland and Jonasson (1992)