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Principles, structure and application of dynamic regional sector model of Finnish agriculture

Heikki Lehtonen

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Principles, structure and application of dynamic regional sector model of Finnish agriculture

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Preface

After I have completed this study I would like to express my sincere thanks to many people and institutions who have provided me guidance and support. It is somewhat exceptional that an engineer works with agricultural sector modelling and policy analysis. First, I use the opportunity of providing a short explanation.

In mid-1990's I was an undergraduate engineering student at Helsinki University of Technology (HUT) at the department of technical physics and mathematics. I gradually became interested in the topics in the curriculum of the Systems Analysis Laboratory, headed Professor Raimo P. Hämäläinen. Applied mathematics and operations research turned out to be an interesting and challenging field of study with many applications. Since many of the graduated students of the Systems Analysis Laboratory were – and still are – employed by energy, finance and telecommunications industries, I believed that studying courses of applied mathematics makes it possible to find jobs with good prospects, at least compared to farm work I was used to do at home, at a farm in Central Finland. I believed that applied mathematics and economic modelling is as far from agriculture as possible. This belief, however, appeared to be an illusion.

In spring 1995 I saw a note at a notice board at HUT. An economic modeller was needed in constructing an agricultural sector model for Finland. I found the task interesting and realised that as a mathematically and economically oriented person with a backround at farm I could be a strong candidate to the position. Prof. Lauri Kettunen from MTTL (Agricultural Economics Research Institute) selected me as a programmer, at first, to the project. There was little to start with when I started my masters' thesis in summer 1995. The work turned out to be very interesting, however, and I have learned a lot during these years. I would like to express my sincere thanks to prof. Kettunen for his generous and extensive support in all phases of the study.

Professors Lauri Kettunen and Raimo P. Hämäläinen encouraged me from the very beginning to find creative solutions to the problems of modelling Finnish agricultural sector. I would like to thank Raimo P. Hämäläinen for his support during the study. I would like to express special thanks to Dr. Juha Marttila for extensive guidance and support at MTTL (now MTT/Economic Research). I also received a lot of help and support from researchers Jyrki Niemi and Hannu Linjakumpu. In applications, which have remarkably improved the model and this study, I have also been working with prof. Ilkka P. Laurila, Dr. Jyrki Aakkula, PhD Jukka Peltola and Lic. Agric. Economics Jussi Lankoski, all from MTT/Economic Research. In later phases of the study I also benefited from the comments of PhD Kyösti Pietola who is now the acting director and professor of MTT/Economic Research.

In the process of finding solutions to problems of endogenous investments and technical change I participated Young Scientist Summer Program 1998 at IIASA, Austria. I would like to thank Dr. Yuriy Kaniovskiy and prof. Giovanni Dosi for encouragement and advice I received at IIASA.

I wish to thank the Graduate School of Systems Analysis, Decision Making and Risk Management, directed by prof. Raimo P. Hämäläinen, for its excellent courses and seminars I have been able to participite. I also wish to thank Finnish Post-graduate Program in Economics for the opportunity of participating PhD courses of microeconomic theory and econometrics.

I am grateful to pre-examiners, professors Svend Rasmussen and Bart Verspagen, for careful reading of the manuscript and for several suggestions which greatly improved the study.

I express my special thanks to Jaana Ahlstedt for editorial assistance. Jaana planned the lay-out of this publication and has provided great help in many practicalities during the various phases of this study. I also wish to thank M.Sc. Jaana Kola for her careful reading of the manuscript when correcting many flaws in the English grammar. Thank you for your constructive professional help.

The major part of this study was financed by MATEUS- and AMALIA-programs of the Ministry of Agriculture and Forestry. All the time I have been working in MTT/Economic Research (former MTTL) and I have enjoyed the nice working conditions and pleasant atmosphere. I express my sincere gratitude to prof. Jouko Sirén, the former leader of MTTL, and prof. Kyösti Pietola, the leader of MTT/Economic Research, who both considered this study important enough to be kept on the research agenda. I also thank MTT/Economic Research for including this study in the “Publications”-series.

I have received grants from Academy of Finland/The Finnish Committee for IIASA (a grant enabling the participation in the Young Scientist Summer Program), Kyösti Haataja Foundation of Okobank Group, and Kyösti and Aino Tiura’s Foundation of Agricultural Research. These grants have enabled the intensive research work necessary for the completion of this study.

I am grateful to my parents who have emphasised long-term commitment to learning and the importance of dedicated and comprehensive work. These values have enabled me to finalise my work to the level of an academic dissertation.

My deepest gratitude and thanks, however, go to my wife Tatjaana who has shown exceptional love and patience in supporting me in the various phases of the study.

Raakel and Eljas, you were born during the evolution of this study. You are the sweetest joy in my life. I dedicate this book for you.

Koivukylä, Vantaa August 28 2001

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Principles, structure and application of dynamic regional sector model of Finnish agriculture

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Abstract. This study presents a dynamic regional sector model for Finnish agriculture (DREMFIA) to be used in evaluating the effects of different agricultural policies on production and agricultural income in Finland. Since agriculture is characterised by the long duration of investments, the economic adjustment to policy changes, like the EU integration and Agenda 2000, is likely to take a long time. Recursive programming has been used in simulating annual market reactions and economic adjustments. A process of adjustments in dis-equilibrium is assumed. The theoretical basis of the chosen modelling methodology is presented and discussed.

Two versions of the model are presented. The base model assumes exogenous efficiency development, i.e. labour and capital inputs needed per hectare and animal, in agriculture. In the Finnish agriculture technical change is largely a policy variable because of the publicly financed and controlled investment aid system. Using the base model one may analyse the levels of production and income at different levels of efficiency development. The technology diffusion model used in the extended version models the change in capital invested in alternative production techniques. The change in capital is affected by the profitability of each technique, as well as the relative spread of each technique, i.e. commonly used techniques are more accessible to farmers. Hence, the new best performing techniques may only gradually replace the existing ones.

In both variants, empirically validated production functions are used in determining the milk yields of dairy cows and crop yields. Feed use of animals is endogenous in the model, as is the number of animals and hectares of crops. Appropriate energy, protein, and roughage requirements of animals are included. Agricultural policy measures are modelled in detail in all 14 production regions in the model. Processing activities of 18 different dairy products have been included. Domestic and imported products are assumed imperfect substitutes (Armington assumption).

It is found that Agenda 2000 results in larger grain areas and farm income in medium term, but in lower milk and beef production volumes in the long term compared to the base scenario. Also farm income will slightly decrease due to the Agenda 2000 dairy reform starting at 2005. It is also found that the long term effects of Agenda 2000 on milk production are larger if the endogenous investments are taken into account in the analysis.

Index words: Agricultural sector model, policy analysis, Recursive Programming, technology diffusion, Armington assumption

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1. Introduction

1.1. The need for agricultural policy analysis

Finnish agriculture faced a drastic change in the economic environment on January 1 1995 when Finland joined the European Union (EU). The national agricultural policy with high producer prices and import tariffs were replaced with the Common Agricultural Policy (CAP) of the EU, characterised by high direct payments paid per hectare and animal. All agricultural products can be traded freely in the EU, while there were considerable import tariffs in Finland before 1995. The aggregate agricultural income in Finland has decreased during the EU membership. Agricultural support constitutes a major part of farmers' income since market prices do not cover the production costs (Hirvonen 2000, p. 141).

The CAP is currently under reform because of Agenda 2000 reforms implemented in 2000-2007 (European Commission 1999). In Agenda 2000 product prices were reduced and the resulting losses to producers were partly compensated by direct subsidies paid per hectare and animal. Such a policy reform was considered necessary because of political pressures for more liberal trade of agricultural commodities and reduction of trade distorting agricultural policies. For Finland, where the production costs per kilo produced are relatively high, such a policy reform means that public subsidies constitute an increasing part of farmers' income.

Some revision of Agenda 2000 and further changes in the CAP are to be expected in the next 5 years. Since the trade liberalisation pressures are likely to lead to lower product prices in the future, the forthcoming agricultural policy reforms will further increase the influence of public policies on agriculture. The agricultural policy measures, including minimum product price levels (through the public intervention system), direct subsidies per hectare and animal, investment aids, production quotas and environmental regulations, affect agricultural production and income of farmers.

There are national interests and clearly stated goals related to the production quantities of agricultural products and farmers' income in Finland (Working group of agricultural policy 1996, p. 107). Hence, the agricultural policy issues receive attention and are frequently under political debate in Finland. There is a need to analyse the effect of different agricultural policies on production, farmers' income and the environment. Policy analysis is an integral part of agricultural policy planning and policy making.

1.2. The need for a Finnish agricultural sector model

The overall system of agricultural policy measures applied in Finland is large and complex because the agricultural sector produces a wide range of different kinds of products and because of the regional dimension. Large economic systems including many interrelationships are often analysed by means of mathematical models. Such models are constructed in order to obtain better understanding of the working of the overall economic system, as well as to provide an analytical tool to be used in policy and other economic analysis. The overall effects of many simultaneous or successive policy interventions may be hard to be evaluated, even qualitatively, without large and comprehensive sector models which take into account the interrelationships, like sector level resource constraints, competition and technical progress. Evaluations based on partial market models of individual products or merely subjective expert evaluations may not take into account internal working and dynamics of an economic system. A well defined and documented model may provide valuable information to be used in evaluating policy effects in large economic systems.

In addition to the actual application and the numerical results of the model, a modelling project forces researches to check their conceptions and understanding of many relevant issues in economic analysis. Causes and effects of economic phenomena and the perceived interrelationships in the agricultural sector need to be put under critical evaluation when setting up and validating an agricultural sector model. Without a long term modelling project and a model it is more difficult to maintain and develop a holistic perspective of the agricultural sector and the linkages between sub-sectors and economic agents. All aspects of the reality cannot, of course, be included into a model. One has to be aware of the limitations of the model and recognise the meaning of the model results, given the initial assumptions.

The model characteristics should depend on the intended function of the model and questions to be answered using the model. Each model should include the relationships and variables which are relevant to the questions at hand. One should not and need not be limited to a certain sub-class of possible sector models but, rather, one should find out what kind of model would be the most appropriate in answering the questions at hand.

Previous sector level models of Finnish agriculture are few. The model of Kettunen (1981) was constructed and applied in a very different context and economic conditions from what the Finnish agriculture is facing now. There is an open competition of agricultural products with the other EU countries, which was not the case before 1995. Kettunen’s model can no longer be used without major revision because of the complex policy system of the EU, which is rather different from the former national policy system. Agricultural support varies in different regions of Finland, and the regional dimension lacking in Kettunen’s model is of great importance in making decisions concerning agricultural policy.

The model of Törmä and Rutherford (1993) is a comparative static CGE-model describing the working of the whole national economy of Finland. Despite the efforts of disaggregating Finnish agriculture into separate production lines, the model of Törmä and Rutherford is still a rather aggregate level description of Finnish agriculture and agricultural policy. The important regional dimension is lacking in the model of Törmä and Rutherford. Consequently, the complex and detailed policy system is rather aggregated. The model also lacks temporal dimension, which cannot be fully neglected since the policy reforms, like Agenda 2000, do not take place simultaneously, but within a specified time interval.

Törmä and Rutherford (1993) analysed the consequences of the expected EU membership in Finnish agriculture. The accession conditions granted to Finnish agriculture were not known when the report was written. Consequently, many assumptions concerning the future prices and subsidies were made. According to the model results, the EU membership has wide-spread allocation effects. Grain production would vanish altogether, and the volumes of other agricultural activities would decrease by 30-50%. The chances to survive would be better in milk and beef production and in the production of crops (except grain). On the other hand, Törmä and Rutherford concluded that the EU membership would bring some efficiency gains, i.e. other sectors would benefit more than agriculture loses. The welfare of the Finnish society was calculated to grow by 1%. Törmä and Rutherford (1993, p. 61) also conclude that the results of the model should not be taken too literally since the calculations are rather “technical by nature”. The aim of the study of Törmä and Rutherford was to show the rough scale and direction of the likely changes caused by the EU membership. It was not intended to be a tool to be used in detailed agricultural policy analysis including regional and time dimensions.

There is an obvious need for a detailed regional sector model of Finnish agriculture. This study presents the process of selecting the appropriate methodology to be applied in such a model, the structure of the model, and the application of the model.

1.3. Objectives of the study

The objectives of this study and thus the model selection criteria (to be employed in Chapter 4) in general level, can be formulated as follows:

1. The agricultural policy system is very detailed and complex including price subsidies, direct payments per hectare and animal, physical production quotas, set-aside regulations, premia for extensive production, and investment supports. All these policy measures are highly relevant for Finnish agriculture, and all of these should be included in the

model, at least implicitly. Since the policy measures are different for each production line in agriculture, all the most important production lines must be modelled explicitly in adequate detail to incorporate the relevant policy measures. Any aggregation across the production lines is not acceptable.

2. Many of the subsidies are changing gradually over time because of the so-called transition period 1995-2000 and Agenda 2000. At the same time, there is a considerable adjustment process on farms in order to adjust to these policy changes. Investment aids are granted for farmers in order to increase production efficiency. Productivity is also increasing in milk and in pork production, for example, which may affect the supply response to policy and price changes in the medium and long term. Because of these continuous changes, a dynamic model describing the development path of agriculture is preferred to static models.
3. Since the support varies according to the region, a regional model consisting of an appropriate number of regions is necessary. Heavy regional aggregation is unacceptable because of the support system, as well as the fact that the production conditions vary greatly in different parts of the country.
4. Since the EU membership integrated Finland to the common EU market for agricultural products, foreign trade should be explicitly included into the model. Import competition, in particular, is a considerable force affecting Finnish agriculture and food industry. Since exports are important for the milk and grain sector, in particular, exports should be included as well.
5. Since the milk sector constitutes around 50% of the annual turnover as well as the total value added of agriculture, the milk sector should receive particular emphasis in the model. It is preferable to have some milk processing industry or simple milk processing activities included, since milk is processed into many products, and many of them are exported.
6. Due to the structural inefficiency of Finnish agriculture compared to many other EU countries, the investment program, investment aids and the resulting increase in production efficiency should be included in the model. One should be able to analyse the effects of investment aid programs.
7. Environmental arguments have gained increasing weight in governmental decision-making on agricultural policy. Thus the environmental effects of agricultural policies need to be analysed. If this is possible by means of the model, such analyses would be most helpful and of great interest to agricultural decision-makers.

Since there are many aspects in the agricultural policy analysis, the model should be flexible, i.e. one should be able tailor the model to more than one specific question. However, all questions of agricultural policy need not be answered by the model, and all parts of the model need not be equally detailed. Different research projects can be launched when applying the model to some specific questions.

This study shows that one cannot meet the objectives stated above by direct application of individual agricultural sector models that can be found in the literature. Modelling sector level dynamics, investments and technical change appears to be a difficult problem. The literature of agricultural sector models is relatively scarce on such issues since most studies are concerned with static models. In addition to a review of agricultural sector models, a more general literature review is necessary in order to evaluate alternative dynamic modelling schemes and techniques. The preferred approach needs to be motivated and presented in detail in this study, together with the overall model structure. It also needs to be shown how the model can be used and applied.

The challenge of this study, in the domain of applied mathematics and operations research, is to tailor a model satisfying objectives 1-7 without making the model too complex and intractable. One needs to select the appropriate methodology and to combine the relevant approaches into a large dynamic model whose parts are consistent with each other. This requires careful evaluation of the existing modelling alternatives. The model to be built is to represent the interplay of economic and technical change.

1.4. Structure of the study

It is relatively easy to present a model and analyse the results. What is also important is to give sound arguments favouring a chosen modelling philosophy and methods. For this reason, one third of this study is devoted to the review of literature and evaluation of the theoretical and methodological basis of the model, one third is devoted to the presentation of the model structure, and one third is devoted to the application of the model.

Modelling entails two key aspects that a modeller needs to be fully aware of: the methodology and the substance. Some features of the substance, i.e. Finnish agriculture, markets of agricultural products, and agricultural policy, are presented in Chapter 2. The selection of the appropriate methodologies is not possible without evaluating the alternative approaches. A review of economic models employed in agricultural policy analysis is presented in Chapter 3. It turns out that the static and standard form of static equilibrium analysis most often used in agricultural sector modelling studies is problematic when applied to Finnish agriculture in the current context. None of the individual models, which are almost all static equilibrium models, in the literature is able to meet all the objectives 1-7 stated above. However, after evaluating the basic approaches, it becomes clear that optimisation techniques should be used in this study instead of econometric ones (Chapter 4). It becomes evident that a dynamic model is needed in order to meet the objectives 1-7. Modelling economic adjustments in dynamic dis-equilibrium framework is more appropriate for meeting the objectives of this study than static or moving equilibrium conceptions.

The theoretical foundations and motivation of the chosen modelling approach are presented and discussed in Chapter 5. The basic concepts of consumer and producer surplus, the sum of which is maximised in sector level optimisation models, is presented in Chapter 5.2. There are relatively few dynamic models in the literature of agricultural sector models. For this reason, another survey of literature and evaluation of dynamic methods is presented in Chapters 5.3-5.4. Chapter 5 provides further motivation why dis-equilibrium dynamics, adaptive economics paradigm, and technology diffusion in a population of heterogeneous enterprises is preferred to purely neo-classical dynamics characterised by inter-temporal equilibrium or equilibrium movements based on strategic behaviour of representative farms.

The structure of the dynamic regional sector model of Finnish agriculture (hereafter: DREMFIA) model is presented in Chapter 6. The reader should note that there are two versions of the model: the base model with exogenous technical change, and the extended model with endogenous technological diffusion. The data used in the model is described in Chapter 7. The scenario parameters used in the applications presented in this study are presented in Chapter 8. The applications of both models are presented in Chapters 9 and 10. The relative strengths and weaknesses of the models and the modelling approach are discussed in Chapter 11. Finally, the main findings and conclusions are presented in summary.

This modelling project should be seen from the viewpoint of operations research: Rather than relying on a single existing model type the aim is to build a model which is the most appropriate to shed light on the given specific questions. Given the limited resources available, however, not all problems reported in various sector modelling studies can be solved. Dynamics is put first in this study, since agriculture is characterised by dynamics linkages and a long-term investments. Knowledge of the empirical substance of the application area of the model is emphasised. The actual production process should not be a black box for a modeller, otherwise the model becomes too abstract from reality, and the actual economic agents as well as policy makers have no confidence in the model results.

2. Finnish agriculture

This chapter presents a brief overview of the economic environment of Finnish agriculture. A more detailed description of Finnish agriculture can be found in MTTL 2000 and in many references cited in this chapter.

2.1. Natural conditions and structural deficiency of Finnish agriculture

In 1999 the area under cultivation was 2.18 million hectares, including 0.21 mill. ha set-aside area. Of the area under arable crops the share of bread grain was 6.6%, that of feed grains (mainly oats and barley) 50%, oilseed plants 3.2%, potatoes 1.6%, sugar beets 1.8% and grass fodder 34.2% (Table 2.2). The areas under horticulture were relatively small. The area under set-aside was relatively large in 1994 due to the national set aside obligations, which were replaced by the EU set-aside obligations in 1995.

Table 2.1. Yield levels of barley (kg/ha) in some regions[1] in Finland.

	Southern Finland	Ostrobothnia	Eastern Finland	Northern Finland	Whole country
1989	3170	3430	3110	2910	3150
1990	3940	3650	3250	3140	3540
1991	4010	3210	1790	2860	3290
1992	2350	3570	3250	1800	2810
1993	4100	3550	2860	2570	3670
1994	3890	3790	3170	2800	3680
1995	3340	3850	3370	3280	3420
1996	3550	3700	2840	2430	3430
1997	3700	3920	3130	2540	3440
1998	2680	2240	1750	2470	2390
1999	1930	3550	2470	1730	2700
Average	3333	3496	2817	2594	3229
Min. Max.	1930 4100	2240 3920	1750 3370	1730 3280	2390 3680
Max. change %	74	58	81	43	31

Source: Yearbooks of farm statistics 1990-1999. Information Centre of the Ministry of Agriculture and Forestry.

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[1] Southern Finland is represented by Uusimaa, Ostrobothnia by Southern Ostrobothnia, Eastern Finland by North Karelia, and Northern Finland by Lapland Employment and Economic Development Centres.

Table 2.2. Crop areas 1990-1999 (1000 ha).

Crop	1990	1994	1995	1996	1997	1998	1999	Max. annual change (%)	Average annual change 1994-1999
Winter wheat	38.1	11.3	12.6	25.2	24.3	30.4	11.9	200	40
Spring wheat	152.5	77.6	88.1	87.3	100.5	106.8	105.8	15	7
Wheat, total	190.6	88.9	100.7	112.5	124.8	137.2	117.7	16	12
Rye	83.0	8.6	20.8	35.3	22.8	36.1	12.3	242	74
Barley	502.5	505.7	516.2	542.5	582.8	578.1	581.0	7	3
Oats	460.7	334.3	329.3	374.4	369.2	386.5	403.9	14	5
Other grains	13.7	10.2	11.2	14.7	18.1	19.1	19.1	31	14
Cereals total	1250.5	947.7	978.2	1079.4	1117.7	1157.0	1134.0	10	5
Cultivated grass (total)	681.9	684.3	754.6	702.2	686.5	681.6	671.4	10	4
Potatoes	36.5	36.5	36.1	34.8	33.2	32.8	32.3	4	2
Sugar beets	31.0	33.9	34.8	34.7	34.9	33.2	34.8	5	3
Oilseed plants	66.4	67.2	85.3	61.7	60.6	64.8	62.5	28	13
Horticulture	N/a	N/a	17.5	15.7	15.4	14.8	14.8	10	3
Area of crops	2088.2	1796.8	1918.1	1942.9	1963.6	1999.8	1965.2	7	3
Set-aside	182.8	505.1	223.2	179.3	161.6	166.5	211.4	56	23
Cultivated area and set-aside	2271.0	2301.9	2141.3	2122.2	2125.2	2166.3	2176.6	7	2

Source: TIKE 1999a, p. 107.

There are considerable variations, up to 80%, in the annual yield levels (Table 2.1). In addition to the great annual variations in the crop yield levels, there are also large variations (up to 70%) in the areas of some crops, like bread grain, in particular (Table 2.2). This is mainly due to the short sowing periods in spring and autumn. Difficult weather conditions during these periods affects the areas of wheat and rye, in particular. Economic reasons, like changes in the prices and subsidies, affect the crop areas as well. Areas of feed grains and potatoes, sugar beets and oilseed plants, however, are relatively stable. Since 1995, 150-300 million kilos of barley and 100-400 kilos of oats have been exported annually while some bread grain (including both wheat and rye) has been imported due to small areas allocated to bread grain, or low yields.

The crop yields in Finland are quite low compared to crop yields in most other countries in the EU (Table 2.3). The average farm size, measured as hectares per farm, is slightly larger in Finland than the EU average. The average size of farms specialised in arable crops in the EU, on the average, was 23 hectares (21 ha in Finland) in 1995. The average size of farms specialised in grazing livestock was 28 hectares in the EU-15 (22 ha in Finland) in 1995.

Hence, there are no major differences between the farm size, measured in hectares per farm, between Finland and the EU average. However, even if considerable economies of scale can be attained in agriculture, no conclusions on unit costs of production can be made on the basis of the average farm size alone, since yields and other conditions differ between countries. Crop yields and size distribution of farms also influence average production costs and competitiveness of agriculture. Countries where the production volumes are large, like France, Germany, the UK, the Netherlands and Denmark, for example, have high yields as well as many large farms. This means that the production costs of arable crops are much lower in those countries than in Finland. The distribution of farm size is very different in Finland compared to many other EU countries. Large farms produce a large share of total production in the EU. In the EU-15, more than 50% of the total agricultural land belongs to farms greater than 50 hectares, while in Finland less than 20% of total agricultural land is used by farms greater than 50 hectares (European Commission 1999a, p. 33). In France, for example, almost 60% of the agricultural land belonged to farms with

Table 2.3. Some key figures of EU agriculture.

	Average crop yield (fodder units/ha)	Milk yields per dairy cow in 1995 (kg/year)	Number of farms in 1995 (1000)	Agricult. area in 1995 (1000 ha)	Area per farm holding (ha) in 1995	Standard gross margin per 100 ha (ESU)*	Average number of dairy cows per holding in 1995	Average number of pigs per holding in 1995
Austria	N/a	3886	221.8	3425	15	223.3	8	35
Belgium	5200	4849	71	1354	19	130.4	31	561
Denmark	5470	6517	68.8	2727	40	130.4	44	518
Finland	*3600*	*5975*	*101*	*2192*	*22*	*71.4*	*12*	*187*
France	5630	5356	734.8	28267	38	81.4	29	157
Germany	5410	5386	566.9	17157	30	92.4	26	118
The Great Britain	5190	5330	234.5	16447	70	60.8	67	593
Greece	4920	3425	802.4	3578	4	136.0	7	25
Ireland	5400	4272	153.4	4325	28	58,4	31	625
Italy	5650	4963	2482.1	14686	6	126.2	19	29
Luxembourg			3.2	127	40	75.7	35	182
The Netherlands	5360	6429	113.2	1999	18	446.8	46	643
Portugal	1690	4944	450.6	3925	9	62.1	7	15
Spain	2520	4332	1277.6	25230	20	43.5	11	61
Sweden	4220	6757	88.8	3060	34	67.2	27	216
EU-15	*N/a*	*5272*	*7370*	*12849*	*17*	*85.5*	*23*	*95*

*: ESU=European Size Unit (ESU=ECU 1200)

Sources: TIKE 1999a, p. 243; MTTL 1999, p. 20; European Commission 1997, p. T/324; European Commission 1999a, p. 32.

more than 50 hectares agricultural area. In the Great Britain, 17% of all farms had more than 100 hectares of agricultural area in 1995, while in Finland only 0.8% of farms had more than 100 hectares of agricultural area. Almost all agricultural area in Finland is used in the cultivation of relatively low valued arable crops (Table 2.2) like barley, oats, grass, and bread grain. These crops can be grown efficiently with little labour input by using appropriate machinery and equipment. High level of mechanisation, in turn, requires a large farm size. Combined with low yields, the low average farm size and a very low number of large farms imply that Finnish agriculture has a serious *structural deficiency* compared to many countries in Western Europe. Inefficient crop production has a negative impact on animal production.

While animal production is negatively affected by low crop yields and relatively inefficient crop production, animal production is less sensitive to natural conditions compared to crop production. Skills and knowledge of farmers and long-term development efforts in animal production, like the work performed in breeding, for example, may partly compensate for the unfavourable natural conditions and small farm size with high production costs. In fact, dairy production is the dominant line of production in Finland, especially in eastern and northern Finland where crop yield levels are the lowest. In relative terms there is less dairy production in Southern Finland, which accounts for more than 50% of the total agricultural area but less than 25% of dairy production. There are long-term traditions of dairy production in northern areas where dairy production has been the only economically sustainable way of farming on most farms. Farmers in southern Finland have had more options. Pork and poultry production is mostly concentrated to southern and western parts of Finland where the crop yield levels are the highest. The cultivation of bread grain (wheat and rye), oilseed plants and sugar beets, is also concentrated to southern and western parts of the country. In Eastern and Northern Finland almost all cultivated area is under barley, oats and (silage) grass. Potatoes can be cultivated in all regions, but the production has concentrated to some regions which have the most favourable soil types for potatoes. Natural conditions have affected the concentration of agricultural production to some specific areas as well as the specialisation of farms to specific lines of production in Finland (Niemi et al. 1995, p. 54-79, 171).

The relatively low farm size affects the profitability of animal production. The average size of pig farms (fattening pigs) is somewhat greater in Finland than in many other countries in the EU, but clearly smaller than in some intensive pork production countries like Belgium, Denmark, and the Netherlands. The average size of Finnish dairy farms is clearly lower than the EU average and much lower than in the UK, the Netherlands and Denmark. A small farm size results in high capital costs and makes it difficult to use labour saving production techniques. The share of fixed costs is close to 50% of the total costs of agriculture (MTTL 2000, p. 88). This, together with difficult climatic conditions result in relatively high production costs compared to many countries in Western Europe.

In addition to this, there is a considerable diversity in the production costs of farms even on specialised full-time farms of the same size. Using the results from book-keeping farms of the year 1995, Riepponen (1998) finds out that the average production cost of milk was FIM 3.56/litre. On 20% of the farms the production costs were less than FIM 3.00/l, and on 50% of the farms the production cost was lower than FIM 3.50/l. When the farms were classified into four groups of equal size on the basis of profitability it was found that the average production costs of the best group were FIM 2.93/l, while the average production costs of the worst group were FIM 4.29/l. The best and worst group differed mainly in terms of labour costs and capital costs (depreciations). The production cost of milk decreased by 8% between 1992 and 1995. There were 376 dairy farms in the sample. The average number of dairy cows per farm was 17 in the sample while the average size of dairy farms was 12 cows in Finland in 1995. The dairy farms in the sample were specialised full-time farms.

According to Riepponen (1998), the average production cost of cereals was FIM 1.96/kg in 1995 when market prices went down from FIM 1.57-2.52/kg to FIM 0.65-0.85/kg. On 32% of the farms the production cost was below FIM 1.60/kg, and on 62% of the farms the production cost was less than FIM 2.00/kg. When the farms were divided into four groups of equal size on the basis of profitability, the production cost on the farms with the highest profit was, on the average, FIM 1.39/kg and in the worst profitable group the production cost was FIM 2.56/kg. Again, the difference in the production costs between farms was mainly due to labour and capital costs. On the average, the production costs fell by 19% between 1992 and 1995. There were 111 cereals farms with the average size of 49 hectares in the sample which is significantly higher than the average farm size in Finland.

Table 2.4. Variation of production costs on bookkeeping farms in 1995 (FIM/kg).

	Cereals	Dairy	Pork
Average cost	1.98	3.56	14.11
Average costs of the best group	1.39	2.93	11.43
Average costs of the worst group	2.56	4.29	15.80
Maximum costs observed	4.46	6.66	20.67
Minimum costs observed	0.80	2.23	7.68

Source: Riepponen (1998).

The average cost of pigmeat production was FIM 14.11/kg on book-keeping farms in 1995 (Riepponen 1998). 18% of the pig farms produced a kilo of pork for less than FIM 11.00/kg, and on 47% of the farms the production cost was less than FIM 14.00/kg. When the pig farms were divided into three profitability groups of equal size, the average production cost in the group with the highest profitability was FIM 11.43/kg while in the group with the lowest profitability the production cost was FIM 15.80/kg. The production costs of pork decreased by 29% between 1992 and 1995. There were 45 pig fattening farms in the sample, of which only 9 farms were located in support region C. Thus the average costs on each support area are by no means representative.

2.2. Change in agricultural policy

According to (Kettunen 1992, p. 9-13), agricultural policy is a set of all measures of the public sector influencing the agricultural sector. Different subsets of agricultural policy are price and income policy, production policy, structural policy and regional policy. Legislation, restrictions, taxation, and various other decisions of the public sector (concerning food safety, for example) affect agricultural production, investments, prices and subsidies. Agricultural policy can also be seen as part of general economic policy.

Before the EU membership in 1995 the agricultural policy in Finland was characterised by relatively high prices compared to the EU and high tariffs on imports for food products competing with the domestic ones. The goals of the national agricultural policy were to guarantee the self-sufficiency of agricultural products in Finland as well as a reasonable level of income for farmers while keeping the retail prices at a reasonable level. The goals of the national policy were also to keep rural areas inhabited, and to improve the structure of agriculture, i.e. to increase the farms size, and make farms more competitive compared to other countries (Kettunen 1992, p. 101; 1995).

The producer prices were negotiated between the state representatives and farmers' union. Increase in the prices of inputs were, at least in some extent, regularly compensated to farmers in the producer prices. Production quantities exceeded domestic consumption. Because of the high domestic price level some export subsidies were necessary. Part of the export costs were paid by farmers. There were also many measures that restricted overproduction, or made the surplus production more expensive for the farmers than staying within the given limits of the production volume. Early retirement schemes were also applied in order to decrease agricultural production (Kettunen 1992, p. 53-61, 105-106; Kettunen 1995, p. 20-21, 33-34).

In 1995 the national agricultural policy was replaced by the Common Agricultural Policy (CAP) of the EU. The goals of the CAP at the EU level are very much the same as the national goals of Finnish agricultural policy before 1995.

The specific means of achieving these goals, however, are somewhat different. There are no direct negotiations on producer prices between farmers' unions and state representatives in the EU, but there are price intervention systems which, in principle, guarantee some minimum price level (Kettunen 1996, p. 36-38; MTTL 2000, 25-28). The main difference between the CAP and the earlier agricultural policy in Finland, however, is that the EU price level is 30%-65% lower than the earlier price level in Finland, and considerable direct subsidies per hectare and animal are paid to farmers. In Finland the role of direct subsidies was marginal and subsidies were mainly price subsidies before 1995.

Producer prices of basic agricultural commodities at the farm gate decreased drastically on January 1st 1995 (Table 2.5). Prices of primary inputs used in agriculture and retail food prices also decreased due to the EU integration, but far less than the producer prices of agricultural products (Table 2.6).

The decrease of producer prices was partly compensated for by direct support, like payments per hectare or animal, as well as specific transitional price supports which were gradually abolished during the transition period 1995-1999. This was to make the sudden change from price subsidies to direct supports smoother. After 1999 producers thus faced the EU price level. Price support for milk, however, decreased only by 30-50% in the most important production regions during 1995-1999. There are considerable price supports for milk in all regions in Finland. Most of the price reduction due to EU membership is compensated through direct payments per animal and hectares through the CAP.

Table 2.5. Development of some agricultural producer prices including production support, 1994=1.

	1994	1995	1996	1997	1998	1999
Milk	1	0.87	0.83	0.83	0.79	0.74
Beef	1	0.68	0.44	0.41	0.44	0.42
Pork	1	0.65	0.49	0.52	0.46	0.41
Eggs	1	0.48	0.47	0.32	0.34	0.4
Poultry	1	0.50	0.53	0.54	0.55	0.55
Wheat	1	0.41	0.43	0.41	0.40	0.39
Barley	1	0.46	0.48	0.47	0.46	0.46
Oats	1	0.47	0.50	0.47	0.45	0.46
Rye	1	0.35	0.36	0.35	0.35	0.34
Potatoes	1	0.95	0.61	0.80	1.05	1.48

Source: MTTL 2000, p. 37; TIKE 1999a. Livestock products include production supports.

Table 2.6. Producer price index (with support) and input price index in agriculture (1990=100).

	Producer price index	Total input price index	Goods and services	Investments	Buildings
1999	58.7	88.1	83.7	97.5	96.9
1998	59.9	88.6	85.4	95.6	95.7
1997	60.5	90.0	87.8	94.6	94.2
1996	61.3	88.0	85.5	93.4	90.4
1995	71.5	86.6	83.6	93.0	91.0
1994	96.0	107.6	107.1	108.8	101.0
1993	96.4	108.2	109.4	105.4	98.6
1992	96.5	105.5	107.8	99.8	98.8
1991	96.6	103.8	105.5	99.5	101.6
1990	100.0	100.0	100.0	100.0	100.0

Source: MTTL 2000, p. 85.

In addition, there are certain direct supports such as compensatory allowances (LFA support), environmental support (including some obligations concerning fertiliser use, for example), nationally financed supports in northern regions and in southern regions in Finland (Figure A-1 in the appendix). The national support paid for producers in the middle and northern parts of the country are generally fixed and permanent by nature, whereas the national aid paid in southern Finland can be considered permanent only for crop production. The national aid for animal production in southern Finland decrease further by 10% until 2003 from the level of 2000 and are valid only until 2003. National aid also include price support for milk whereas other national supports are paid directly per animal and hectare. The future level of support for animal production in Southern Finland after 2003 are to be negotiated by the EU and Finland. If no agreement is reached the animal producers in Southern Finland receive much less support than animal producers in the other parts of the country. Agricultural investments are subsidised by a specifically tailored investment aid program (to be discussed later). All these aids have to be approved by European Commission, as well as all the other Member States in the EU.

The total value of the national budget support, paid by the State of Finland, decreased steadily during 1995-2000 while environmental support, which is part-financed by Finland and the EU, increased until 1999 (Figure 2.1). Hence, while CAP supports, paid in full by the EU, and LFA support, part-financed by the EU, changed only slightly in 1995-1999, the total agricultural aid has decreased during 1995-1999.

From the year 2000 the CAP supports increased because of the increasing direct compensatory payments due to Agenda 2000 (European Commission 1999b). The Agenda 2000 was made in March 1999 by the EU ministers of agriculture in order to reform the CAP system to better account for the WTO negotiations on agricultural trade liberalisation and the eastern enlargement of the EU taking place during the next ten years. According to the Agenda 2000, cereal prices are reduced by 15% 2000-2001 and beef prices by 25% 2000-2002. Milk prices are decreased 2005-2007 by decreasing the intervention prices of butter and milk powder prices by 15%. These price reductions will be partly compensated for by direct payments per hectare or per animal. There is a supplementary area payment of 19 euros per ton (of a fixed reference yield per hectare) applicable in Finland from 2000, which also slightly increases the CAP support. LFA support is extended to cover the whole country (earlier some very southern regions were excluded from the LFA support) from 2000, and this increases the total value of LFA payments by roughly FIM 800 million. On the other hand, there are some cuts in the environmental support resulting in FIM 400 million reduction in environmental support. There is a FIM 100 million decrease in the national support in 2000 as well. In total, the policy changes will result in a FIM 1.4 billion increase in the total value of agricultural support paid in Finland in 2000 (amounting to FIM 9.4 billion) (MTTL 2001). However, the expected increase in agricultural income is smaller than FIM 800 million be-

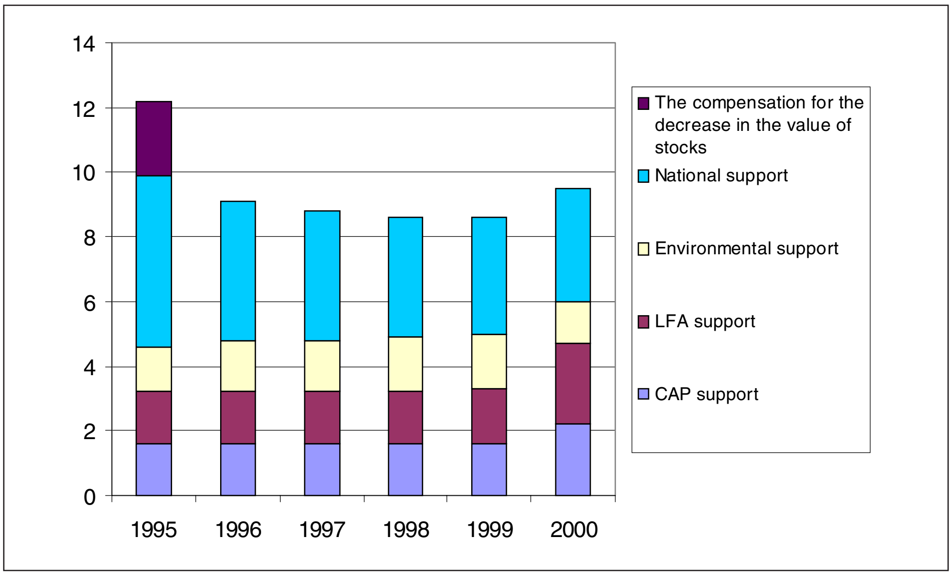

Figure 2.1. The overall value and composition of the agricultural subsidies in Finland (FIM 1000 million).

cause of increased input prices, and because the price reductions of Agenda 2000 are not fully compensated for by direct payments.

The aggregate agricultural income has decreased by 30% during 1995-1999. This is mainly due to the price reductions and gradual decrease in supports. The decrease in input prices has not compensated for the decrease of gross revenues (Table 2.7). Agricultural income of basic agricultural production has decreased by 32% until 1999 from 1994. One should note, however, that the total calculation presented in Table 2.7 is based on real cash flows. Some incomes, like support payments to farmers, in particular, are often delayed and paid in the following year. This result in a smoothed pattern of agricultural income, since the money flows are not causally linked to the production activities of a particular year. There was a crop failure in southern Finland in 1998 and 1999. Compensations for crop damages covered only a fraction of the financial losses to farmers. On the other hand, in 1994 a relatively good crop was harvested. Despite some annual fluctuations, however, it is evident that the agricultural income has decreased during 1994-1999.

The emphasis in agricultural support shifted drastically from price support to direct payments in 1995. This means that the earlier production practices became clearly sub-optimal after the EU integration. This means that farmers have incentives and pressures to adjust to the changed economic environment.

The farm level calculations based on large sample farm accountancy data (consisting of 1,100 farms in different parts of the country) show that profitability of agricultural production has clearly decreased during 1994-1999 (Ala-

Table 2.7. Total calculation of agriculture (excl. horticulture) at 1999 prices, FIM mill.

	1993	1994	1995	1996	1997	1998	1999
Crop production	4361	5192.1	1812.2	2227.7	2353.7	2057.4	1943.0
Animal production	13175.0	13476.4	7892.1	7949.1	8186.3	8081.6	7927.2
Gross return at market prices	17536.0	18668.4	9704.3	10176.8	10540.0	10138.9	9870.2
Stock compensation			2281.8				
Compensations for crop damages	133.0	7.9	11.9	34.0	7.0	20.0	301.4
Income from rents	515.2	419.1	365.4	372.1	366.5	361.0	374.8
Total support	4278.7	4095.9	8003.4	8833.2	8495.4	8197.5	8266.4
Gross return total	22462.9	23191.3	20366.8	19416.1	19408.9	18717.4	18812.9
Production costs	16507.5	15563.2	13513.1	13706.6	13610.3	13742.9	13642.8
Farm income	5995.4	7628.1	6853.7	5709.5	5798.6	4974.5	5170.1
Change		+27.2%	-10.2%	-16.7%	+1.6%	-14.2%	+3.9%

Source: Hirvonen 2000, p. 87-88.

Mantila et al. 2000). The agricultural income per hectare, for example, which can be considered a measure of profitability of agricultural production, decreased in almost all farm types in all regions during 1994-1997 when compared to the average of the years 1992-1994. During 1994-1997 the income per hectare decreased 16-28% on dairy farms (different reduction occurred in different regions), 9-14% on pig farms, 48-65% on beef farms, 19-36% on cereal farms, 50% on egg farms, and 12% on poultry farms.

According to static farm level calculations (keeping production and input use levels fixed to 1997 levels), the profitability decreased further during 1997-1999 on most farm types, but some increase in profitability was observed on beef and egg farms which suffered a considerable loss in profitability during 1994-1997. During 1997-1999 the income per hectare decreased 2-7% on dairy farms, 40-43% on pig farms, 9% on poultry farms and 8-22% on cereals farms. The income per hectare increased 0-17% on beef farms and 33-37% on egg farms. The increase of income per hectare on egg farms was due to record low producer prices of eggs in 1995, which recovered in some extent in 1996 and 1997.

Since farmers may vary the use of inputs, conditional on the amount of fixed assets, the static calculations based on fixed use of inputs (as assumed by Ala-Mantila when calculating the changes in profitability in 1997-1999) give a somewhat pessimistic view of the profitability development. One should also note that *income per farm* may not decrease as much as profitability since the average farm size has increased. Many farms have exited production and some farms have expanded since 1994. The reported considerable reductions of income per hectare, however, indicate the decreased profitability. Farmers have not been able to fully cover the decrease in profitability due to the EU integration by changing the amount of inputs.

2.3. Investments in agriculture

Agricultural investments play a major role in the adjustment to changed economic conditions. Agricultural investments decreased by more than 50% in 1991-1992, and they remained on a very low level during 1991-1995. This was due to the general economic recession in 1991-1993 as well as the increased uncertainty due to the forthcoming EU integration (Figure 2.2). The investments were considerably below the normal levels until 1996 when the uncertainty of future prices and subsidies decreased due to the political decisions concerning agricultural supports. Also agricultural investment aid program triggered investments. The level of investment activity doubled from the 1994 level until 1997, but did not reach the record high level of the late 1980s. There was some cumulative need for investments because of the low investment activity during 1991-1995.

Farmers who invested in modern efficient production techniques were able to benefit from the price support and could pay back some part of their loans already before 1999. However, the level of investment activity decreased in 1999 compared to 1998 and 1997. For example, the number of investments in pig farms decreased from 600 investment projects in 1997 to 200 projects in 1999. This is due to the decreased EU price level of pork as well as the termination of the transition period and transitional aid for pig farms (PTT 2000, p. 48). On the other hand, the number of pig farms decreased by 15% during 1996-1998 (TIKE 1996, 1999a). There were 4,300 pig farms in Finland in spring 2000 (Kallinen 2000, p. 44). 1,500, i.e. 35% the existing pig farms invested and received investment aid during 1996-1999. The aid totalled FIM 304 million of direct support and interest-rate subsidies (MTTL 2000, p. 62-63). It is expected that the number of investment projects in pig sector will slightly decrease 2000 and after this.

Dairy farms have also invested heavily during 1996-1999, but relatively less than pig farms. This is partly due to the production quotas which make the structural change less flexible in dairy production than in pork production. During the last two years the dairy farms, however, account for a larger share of all agricultural investments. 1,300 dairy farms received investment aids in 1999 and 1,100 dairy farms in 1998 (PTT 2000, p. 48). During 1996-1999 a total of 3,100 dairy farms received investment aids totalling FIM 675 million in direct support and interest-rate subsidies (MTTL 2000, p. 63). There were 24,000 milk supplying dairy farms in Finland in 1999 and 22,000 in June 2000 (MTTL 2000, p. 85; Maaseudun Tulevaisuus 2000, p. 4). Fewer than 13% of the existing dairy farms invested in production buildings during 1996-1999.

Investment aids were granted for 200 broiler halls, 500 beef production buildings, 200 other livestock production buildings, and for 4,900 investments in other buildings. In total, more than 10,000 buildings investments were made in 1996-1999. During this time there were also 3,900 joint machinery investments of two or more farms, and 5,600 purchases of additional land. There were 4,200 land improvement projects and 2,800 start-up farming investments aided by investment subsidies in 1996-1999. There were also close to 10,000 environmental protection investments in 1996-1999 due to EU regulations (MTTL 2000, p. 62). Such investments, however, do not influence production efficiency and the production costs. One can conclude that, despite the increased investment activity, a majority of the existing farms have not committed to any considerable investments which could lower their production costs. During the next ten years a majority of the existing farms face a situation where their production facilities, typically set up in the 1980s, are wearing off. These farms have to decide if they invest in new production facilities or if they exit production.

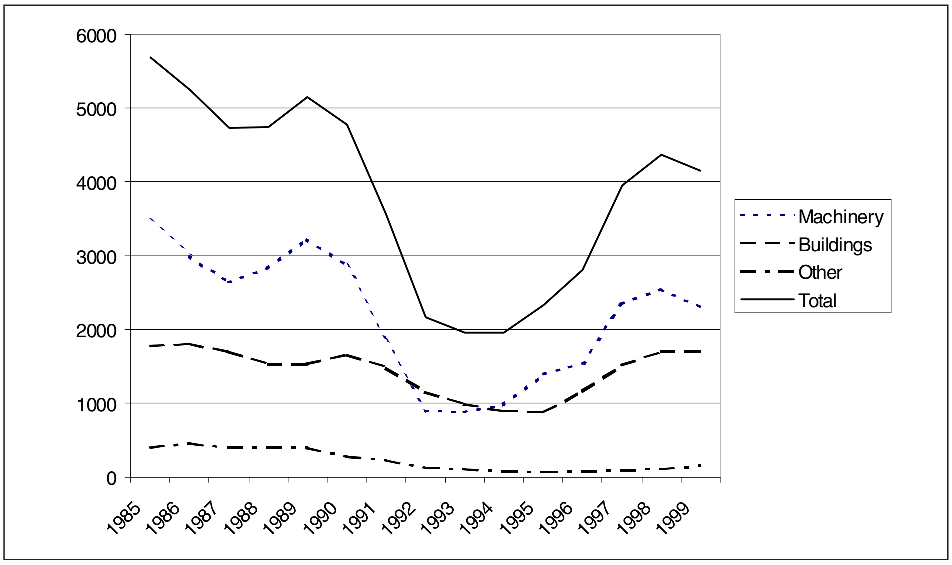

Figure 2.2. Agricultural investments (million FIM) in Finland 1985-1999 (PTT 1998, 2000).

Record high levels of investments such as observed in the late 1980s have no longer been achieved. This is partly due to the decreased prices and profitability as well as the reduced number of farms during 1992-1996 (Table 2.11). The uncertainty of agricultural policy after 2000 has also made farmers rather cautious in making investments. The existing production equipment is used longer and more efficiently than before. Thus the use of fixed inputs per hectare and animal has decreased and the total value of agricultural production facilities has decreased in the last ten years (Lehtonen et al. 1999, p. 122-123).

Investment aid has covered 10-50% of the investment expenditure of individual farms since 1996. On the average, the share of investment aids of the total investment expenditure has been 20-25%. This level of investment support is expected in the future as well. There are also conditions, stated by the Ministry of Agriculture and Forestry, on the minimum size of the farms eligible for the investment aids (MTTL 1999, p. 58). This, together with the large financial support, means that agricultural investments are quite state controlled and the level of investment activity can even be considered a policy parameter in Finland. Few farmers are willing to invest without any aid since other farmers receive the investment aid as well.

2.4. Recent changes in production, consumption and foreign trade

After the EU integration Finland became a part of the free internal market area of agricultural products. When exporting outside the EU, exporters are paid some export subsidies in order to compensate for the gap between the EU prices and world market prices since the EU price level is most often higher than world market prices. The EU has specific intervention systems for beef, butter, milk powder, wheat and barley, for example, in order to guarantee producers a certain price level. Thus national export subsidies are no longer needed and there is no actual need to restrict production. Some production quotas, however, are imposed on milk and sugar production, and the area under oilseed plants is also restricted. In many respect, the CAP system is rather similar to the one Finland used to have before the EU integration (Kettunen 1995, p. 33-34). However, the internal price level of agricultural commodities is not adjusted regularly on the basis of the input prices as was the case in Finland before 1995. The fixed level of intervention base prices implies that inflation of input prices is not compensated to farmers. Farmers need to cover the resulting decrease in income by decreasing the use of inputs per unit produced.

The imports of meat, cheese, and cereals, in particular, have increased since 1994. The imports of bread grain have increased since 1994, partly due to decreased areas or low crop yields of bread grain. Exports of feed grains, i.e. barley and oats, have continued at a high level. In 1998 and 1999, however, the grain exports decreased because of crop failures due to exceptionally unfavourable weather conditions. Exports of meat have decreased in 1995 and 1996 from the 1994 levels, but increased again in 1997 due to increased pork production. Imports of beef and pork have gradually increased since 1995 (Table 2.8).

Table 2.8. Imports and exports of certain agricultural products (1000 tons).

	Beef		Pork		Poultry		Eggs		Butter		Cheese		Cereals	
	Imp.	Exp	Imp.	Exp	Imp.	Exp	Imp.	Exp	Imp.	Exp	Imp.	Exp	Imp.	Exp
1992	0.2	16.2	0	13.4	N/a	N/a	0	11.9	0	17.3	2.5	24.9	82	718
1993	0.8	14.5	0.7	15.0	N/a	N/a	0	15.1	0	16.6	2.6	24.9	11	762
1994	4.6	12.4	1.5	20.5	N/a	N/a	0	18.3	0	22.6	3.5	27	130	991
1995	8.0	4.1	11.7	7.3	2	N/a	0	13.8	0.8	18.3	6.6	29.5	196	385
1996	5.5	5.8	11.3	13.4	1.2	N/a	0	14.1	0.9	21.9	11.6	28.6	206	380
1997	8.2	9.0	10.9	22.8	2.7	N/a	0.1	12.9	0.5	26.8	17.6	31.6	228	621
1998	11.5	5.0	12.7	19.7	2.5	N/a	0.1	10.7	0.6	26.3	18.2	28.5	390	473
1999	11.9	5.0	15.3	22.0	3.2	N/a	N/a	7.5	N/a	30.2	18*	23	282*	337

*: January-November 1999.
Sources: MTTL 2000, p. 45-46, TIKE 1999a.

Table 2.9. Development of retail (consumer) prices of agricultural products, 1994=1.

	1994	1995	1996	1997	1998
Milk, regular	1	1	0.98	0.99	0.98
Cheese (Edam)	1	0.89	0.87	0.88	0.90
Butter	1	0.82	0.82	0.84	0.87
Beef	1	0.87	0.77	0.73	0.74
Pork	1	0.77	0.75	0.76	0.77
Eggs	1	0.56	0.66	0.64	0.67
Wheat flour	1	0.67	0.65	0.65	0.72
Rye flour	1	0.74	0.67	0.69	0.69
Potatoes	1	1.02	0.78	0.86	1.01

Source: TIKE 1999a, p. 177.

The decreased producer prices (Table 2.5) caused considerable changes in consumer prices (Table 2.9). The retail prices of eggs, in particular, decreased drastically by 44% in 1995. Pork prices fell by 33%, and the retail prices of beef, cheese and butter also fell in 1995. Since 1995 the retail prices of many food items have increased only slightly. The retail prices of liquid milk and potatoes were largely unaffected by the EU integration. The retail prices of liquid milk, however, have slightly decreased due to more intense domestic competition between the dairy processing companies.

The reductions in retail prices in 1995, however, did not always cause any increase in the consumption. There are quite clear trends in the consumption of different food items. The consumption of liquid milk and butter has decreased steadily, while the consumption of cheese and poultry meat has increased (Table 2.10, Figure 2.3). The strong upward trend in poultry meat consumption was fostered by the decreased producer and retail prices in 1995, while the downward trend in the consumption of beef and eggs was temporarily changed to an increase in consumption in 1995. The downward trend in the consumption of beef and eggs, however, has continued after the price shock in 1995. The decrease of retail prices of butter by 18% in 1995 influenced the consumption very little. On the other hand, pork consumption increased by 12% up to 33.3 kilos per capita in 1995, and the consumption was more than 34 million kilos per capita in 1998 and 1999. It seems that pork consumption has slightly increased after 1995. Poultry meat consumption, however, increased as much as 62% between 1994 and 1999 and 45% between 1995 and 1999. It seems that the upward trend in poultry consumption will continue.

One can conclude that it is quite difficult to forecast the effect of retail price changes on food consumption. It is also difficult to estimate the price elasticities

Table 2.10. Consumption of certain food items (kilos or litres per capita).

	Liquid milk	Butter	Cheese	Beef	Pork	Poultry	Eggs
1990	222.9	5.5	13.8	21.8	33.0	6.8	11.1
1991	215.7	6.1	13.8	21.3	32.9	7.2	10.7
1992	214.6	5.8	14.3	21.1	32.6	7.4	11.0
1993	211.9	5.6	14.3	18.9	30.8	7.3	10.7
1994	207.5	5.4	14.5	19.0	29.7	7.8	10.4
1995	203.2	5.3	15.3	19.4	33.3	8.7	11.8
1996	203.8	4.9	16.2	19.1	32.9	9.9	11.0
1997	199.4	4.5	16.4	19.3	32.2	10.7	10.4
1998	192.5	4.4	17.0	19.2	34.1	11.9	10.3
1999	190.8	4.1	17.2	18.8	34.4	12.6	9.9

Source: MTTL 2000, p. 43.

of demand for many food items because of the persistent trends (changing preferences) and in-responsive demand, or because of the fact that the consumption may first increase due to the price reduction and then increase again despite further slight price increases (pork). In the case of beef, the consumption was increased slightly in 1995 due to a price reduction of 13% and then decreased in 1996 despite a further price reduction of 11%. In 1997 the price of beef de-

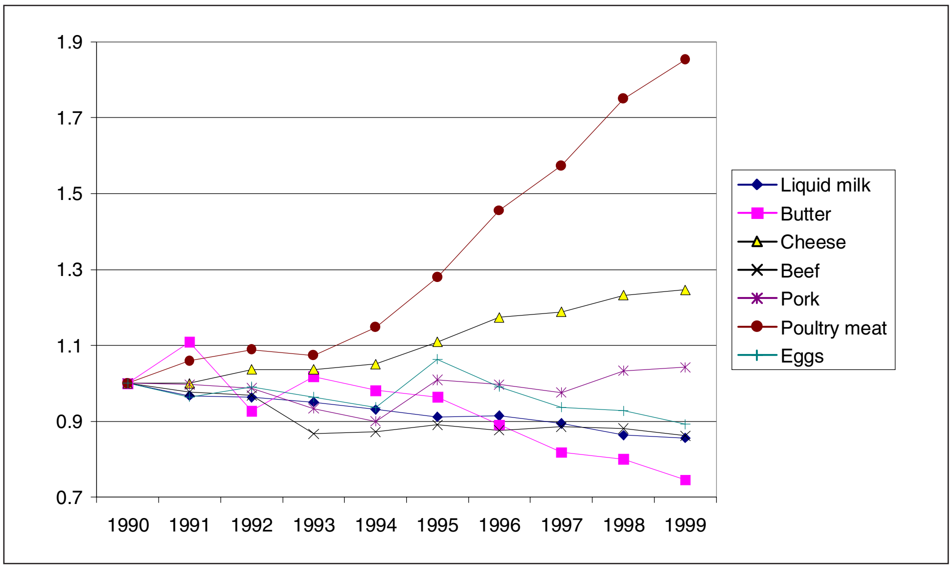

Figure 2.3. Consumption of certain food items, 1990=1.

creased by 9% and beef consumption increased again by 1%. Thus one may derive price elasticities of demand of different signs when using data from slightly different time periods. One may conclude that the observed persistent trends are safer for forecasting future changes in food consumption than relying on price elasticities of demand estimated using past data.

Consumers seem to prefer domestic food, particularly meat, to imported food. According to Finfood (1999), consumers are increasingly interested in the ways how the agricultural products are produced. The importance of the origin of the food products in the consumer choices has increased since 1995. At the same time, price has less effect on consumer choices. In particular, when buying fresh meat, more than 80% of the consumers always choose the Finnish product when both imported and domestic products are available. Animal disease problems and food scandals (like BSE, swine fever and dioxine scandals) in the other EU countries have probably reinfoced this preference.

The oligopolistic competition of food industry as well as retail business affect the producer prices of agricultural products. Meat processing firms have been obliged to make long-term contracts with retail chains. Consequently, the producer prices of pork, for example, have lagged behind the price changes in the EU, and the changes in producer prices have been smaller in Finland than on the EU markets (MTTL 2000, p. 37). Some producer prices have occasionally been lower or higher than the average EU market prices. Sometimes the producer prices of barley, offered by the food industry, have been slightly lower than the intervention prices. In 1998 the market price of barley in Finland was 2-3% below the EU market price (MTTL 1999, p. 33).

The production volumes of some agricultural products, like milk, pork, and poultry meat have increased since 1995. The increase in pork production is due to the many investments in 1996-1999. For the same reason, milk production has increased slightly over the quota limits. Poultry production has increased mostly by joint efforts of producers and meat processing industry in response to the increased demand (Table 2.11).

It is interesting to see that the production volumes of many commodities have increased during 1994-1999 despite the reduced profitability of the production. The production of beef, however, has decreased considerably since 1995. According to Ala-Mantila et al. (2000), the profitability of beef production in all parts of the country decreased 50-65% during 1994-1997 but improved slightly in 1998 and 1999. There were less than 7,000 specialised beef farms in Finland in 1999, and the average size of these farms is small. 44% of beef farms had less than 15 hectares arable land in 1996 (Lehtonen et al. 1999, p. 36). Most of the beef supply comes from dairy animals. The number of dairy cows is constantly decreasing, however, due to the fixed production quotas and the increasing milk yields per dairy cow, which implies a decreasing beef supply from the dairy animals. The number of beef farms decreased by 2,100

Table 2.11. Production volumes of certain agricultural products (1,000 tons or million litres), average annual yield of dairy cows (kg), number of milk suppliers, pig farms and total number of active farms (1,000).

	Milk to dairy mill.l.	Beef 1000 tons	Pork 1000 tons	Poultry meat 1000 tons	Eggs 1000 tons	Average yield of dairy cows (kg)	Number of dairy cows (1000)	Number of milk suppliers (1000)	Number of pig farms (1000)	Number of active farms (1000)
1992	2274	117	176	36	67	5613	428	36	6.9	121
1993	2264	106	169	35	70	5648	426	35	6.7	116
1994	2316	107	171	39	72	5869	417	34	6.6	115
1995	2296	96	168	42	75	5982	399	32	6.2	100
1996	2261	97	172	49	71	5993	392	30	5.9	94
1997	2301	99	180	53	67	6183	391	28	5.6	90
1998	2300	93	185	61	63	6225	383	26	5.3	88
1999	2325	90	183	66	59	6443	374	24	N/a	81*
Max. annual change (%)	2.3	10.3	4.7	16.7	6.3	3.9	4.3	7.7	6.1	13.0
Average annual change (%)	1.1	4.7	2.5	10.0	5.0	2.0	1.9	5.6	4.3	5.1

*: Number of farms eligible for support in 1999
Sources: MTTL 2000, p. 35, 85. TIKE 1996, p. 25, 85.

farms between 1994 and 1996. There were 7,600 farms specialised in beef production in Finland in 1996 and 6,700 in 1998.

The number of poultry farms was 2,000 in 1996 and 1,600 in 1998. There were also 41,000 farms specialised in plant production, 1,000 farms specialising in forestry and 5,500 other farms. In total, there were 88,000 active farms in Finland in 1998 (TIKE 1999b).

3. A review of economic models used in analysing the agricultural sector

3.1. Economic models of agriculture

The economic models describing agriculture can be grouped or classified in many ways. One way is to make a distinction between international trade models, national economy-wide models, sector-level models, partial market models of certain individual or a group of agricultural commodities, or individual farm level models (Jensen 1996, p. 8).

3.1.1. General equilibrium and partial equilibrium models

GE models are applied both in international trade models and when modelling national economy in individual countries. In GE models agriculture can be modelled as one quite aggregated sector in the economy. GE models are designed to represent the overall functioning of national economy. Thus GE models have a large variety of potential applications, whereas partial equilibrium models concentrate on representing only one sector or a product in the economy. In GE models the interaction between the sectors in the economy are characterised by different flexible model structures as well as input-output tables or social accounting matrices which characterise money flows between different sectors in the economy. The inputs, if not defined as fixed inputs in short-term analysis, are mobile across the sectors of the economy, and the prices of all products are determined simultaneously in a GE model (Pindyck and Rubinfeld 1995, p. 559). Perfect competition results in optimal production and consumption allocations as well as in optimal allocation of resources in the economy. The total welfare is also maximised (Silberberg 1990, p. 492-493). Impacts of a variety of public policies, for example, can be evaluated using GE models. Törmä (1989) and Törmä and Rutherford (1992) use a CGE model in analysing tax reform in Finland. They also performed a simple analysis of the EU integration of Finnish agriculture (as summarised in Chapter 1) (Törmä and Rutherford 1993).

In sector-level PE models the demand and supply of agricultural products are modelled in more detail, but other sectors in the economy are neglected. Partial equilibrium models describe one sector or only one product or a group of closely related products in the economy. PE models neglect inter-sectoral linkages and require some exogenous variables describing, for example, input prices and wage rate.

Partial market models, which can be considered a subset of PE models, describe supply and demand of a single product or a group of closely related agricultural commodities without linkages to other production lines in agriculture. The scope of partial market models, however, is rather limited, since different production lines in agriculture are closely related to each other. For example, animal production is dependent on fodder production, and areas of different crops are dependent on the profitability of all other crops. Thus, only rather limited conclusions can be drawn when using partial market models. This is especially true in the case of major changes in the supply, which may imply changes in factor prices in agriculture. The logic applies when comparing sector level PE models to GE models in general. If supply and relative prices change remarkably, PE models may give quite misleading results since resource allocation between the sectors is not taken into account. More general models may produce more reliable aggregate level results, while PE models of a single commodity, for example, provide a detailed description between supply and demand as well as appropriate policy variables. Agricultural policies, like CAP (Common Agricultural Policy of the European Union), vary considerably across agricultural commodities. Some commodities are subsidised and more regulated than others. When aggregating and lumping such commodities together, the identification of alternative policies will be lost, and little can be said about policy effects that would carry any weight among agricultural policy makers (Salvatici et al. 2000, p. 15). Because of an ability to carry a considerable detail of products and policy instruments, PE models have an advantage over GE models where aggregation of many agricultural commodities is usually inevitable.

In countries like Finland agriculture is a small sector in the national economy (in terms of value added) and its effect on other sectors is very small. In such a case the feedback from national economy to agriculture is negligible, and there would be hardly any difference in the model results if a sector-level model were expanded to a GE model (Tyers and Anderson 1992, p. 198). If agriculture is a small part of national economy, and if there are no great changes in national economy, PE models can be considered adequate in modelling agriculture. One advantage of PE models is the relatively simple structure compared to GE models. Also, the results may be easier to understand and interpret. It is also easier to embed dynamic and stochastic features in PE models than in GE models (Hubbard 1995, p. 165). The total quantity of products, inputs and resources may expand in PE models, which is not the case in standard Computational General Equilibrium (CGE) models (excluding growth models) (Silberberg 1990, p. 491-493).

In general equilibrium models agricultural products are often more aggregated than in partial equilibrium applications. This is necessary in order to limit the complexity of the model and to improve its computational feasibility. Because of aggregation, the interaction and causal linkages between different agricultural production lines are rather weak in large CGE models (Tyers and Anderson 1992, p. 156-157). Inclusion of some agricultural policy measures, like set-aside obligations, physical production quotas and direct payments into the model is often difficult. This deficiency is due to the heavy aggregation of agricultural production and the inadequate representation of physical resource constraints in CGE model. It is common in standard CGE models that only one “representative” product is produced in each sector of the economy (Banse and Tangermann 1996, p. 5).

If agriculture is a significant part of a national economy such that it has a substantial impact on national economy, or if remarkable structural changes are to be expected in national economy, which, in turn affect agriculture, then general equilibrium approach is preferable to partial equilibrium approach (Brockmeier et al. 1996). In the case of great changes in national economy, PE and GE models may give very different results, since the general economic conditions, like resource allocation, product flows between the sectors as well as prices of inputs of agricultural production, may change considerably. This fact has been observed in some studies when examining the effects of agricultural trade liberalisation on developing countries and the effects of the eastern enlargement of the EU on Eastern European countries (Hubbard 1995, p. 165-166; Banse and Tangermann 1996).

3.1.2. International trade models

International trade models are applied in analysing changes in the trade flows of agricultural commodities as a consequence of economic changes or changing trade and agricultural policy. International trade models are mostly static and both General Equilibrium (GE) (like GTAP: Hertel 1997) and Partial Equilibrium (PE) (like the models used by Banse and Tangermann 1996 or Tyers and Anderson 1992, for example) is applied.

According to Tongeren et al. (2000, p. 8), who reviewed 18 agricultural trade models, many PE models treat international trade in homogenous products, while GE models deal with trade in differentiated (by origin) products by default. Such pattern may be explained by the fact that there are ready-made templates (like GTAP models and model libraries in many softwares) and an exhaustive literature (starting from Shoven and Whalley 1984) available in GE modelling, while PE models in standard textbooks of economics, as well as in many classical applications, assume homogenous products. If intra-industry trade is excluded and the analysis is limited to net trade, the partial models do not fully capture the interrelationships between different countries. Thus, it is also difficult or impossible to incorporate bilateral trade policies. Consequently, by treating all products as homogenous, PE models have a strong tendency to (unrealistic) overspecialisation.

According to van Tongeren et al. (2000, p. 7), comparative statics is not yet out of fashion in the profession of agricultural trade modelling. There are, however, some dynamic specifications of agricultural trade models. Dynamic features can be incorporated in equilibrium models in many ways. According to van Tongeren et al. (2000, p. 3), the most frequently used approach in agricultural trade models is to specify a recursive sequence of temporary equilibria. Recursive dynamics, however, does not guarantee time-consistent behaviour, which contrasts with inter-temporal equilibrium models. However, explicit introduction of time is appealing to users of the models, since the model outcomes are related to concrete time periods. Thus, dynamic specifications, like increasing productivity between the short and long runs, have been added comparative static models without explicit modelling of the dynamics. By and large, many complications arise when building large dynamic trade models. For example, when applying PE models in a dynamic setting one has to make many assumptions on the development of a large number of exogenous variables. In fact, a large part of the model outcome and the projected future may not derive from the model itself, but from exogenous variables and assumptions. One also needs to check the mutual consistency of the assumptions, since there are no internal consistency check in PE models.

There seems to be two main approaches in estimating the parameters of agricultural trade models: econometric estimation and calibration (van Tongeren et al. 2000, p. 5). To be consistent, econometric estimation of parameters should be done by simultaneous estimation methods that take into account the overall model structure. Unfortunately, this is not usually possible due to the large size of the model, identification problems, data problems, etc. Thus, one has to use single equation methods, using either time series or cross sectional data. Most applied trade modelers, however, use calibration methods, or a so-called "synthetic approach": to generate a set of parameters that is consistent with both the benchmark data and the theory underlying the model. The calibration takes initial estimates of elasticities (like price-, substitution and income elasticities, budget shares in demand systems, input cost shares in supply systems, or Armington substitution elasticities in import demand) from outside sources and adjusts certain other parameters in the given functional forms to the initial equilibrium data set. Calibration therefore exploits theoretical restrictions, equilibrium assumptions and assumptions on functional forms.

What is striking, however, is that 15 out of the 18 models reviewed by van Tongeren et al. (2000) rely on calibration methods, and take initial parameter estimates from the same published sources that sometimes date back a considerable time. It seems that recent trade models of agricultural products are dominated by theory over empirical facts and observations. Econometric estimation of key behavioural parameters, which greatly influence policy response, is considered an underdeveloped area in agricultural trade modelling (Tongeren et al. 2000, p. 9).

It seems that model estimation and the validation of agricultural trade models is lacking generally accepted validation procedures and criteria which could be supported by statistical methods. This, combined with the fact that the documentation of agricultural trade models is often rather weak and scattered (with some exceptions), raises doubts on the validity of the results of agricultural trade models in general. However, there is an increasing transparency in modelling projects because source codes and data are made publicly available in some trade modelling projects (Tongeren et al. 2000, p. 9).

3.1.3. Farm level models

In addition to PE and GE level models, which describe commodity markets and supply – demand relationships, there are farm level models which describe the agricultural production. Such models are very detailed in terms of production compared with PE or GE approaches. Farm level models can provide valuable information on farm level impacts of different agricultural policies with given prices and subsidies. Farm-level models may, for example, be based on linear or non-linear optimisation procedures with risk aversion (Hazell and Norton 1986, p. 9-134). In some cases, some qualitative sector-level results can be obtained using a farm level model. For example, if a representative farm-level model specialises in producing a certain product because of changes in agricultural policy, a similar but possibly smaller relative change could be expected on the aggregate level. Farm level models can also be very simple spreadsheet applications with given prices and production quantities. Such models can be used, for example, in comparing the short-term effects of agricultural policies or a change of input prices on farmers' income in different farm types or in different regions. Such information is used in governmental decision-making and in allocating funds to different support categories. Agricultural models constructed in Finland have mostly been farm level models (e.g. Ala-Mantila 1998).

3.2. Agricultural sector models

3.2.1. Scope and purpose of agricultural sector models

"Sector model" has no exact meaning in agricultural economics. In literature one can find different meanings in different contexts. Agricultural sector may include not only agricultural production but also food industry, retail chains, input industry and some service firms. The minimal condition for a model to be called a "sector model" seems to be that all the most important agricultural products and their supply and demand (either from consumers or from food industry) are included (Bauer 1988a, p. 4; Hanf 1988, p. 355; Hazell and Norton 1986, p. 125).

An agricultural sector model can be understood as a multi-input- multi-output- model which includes various internal linkages within and between different production lines in agriculture. The linkages between the production lines, say, between animal and crop production differentiate sector models from partial market models which include individual products or groups of similar products. In a sector model the level of detail need not be any lower than in partial market models. Relationships between different production lines and some physical resource constraints make it possible to analyse agriculture as an interrelated system. This is necessary, since some policy measures, like set-aside regulations, base areas and CAP support (which is paid in equal amount to most, but not to all crops), concern all production lines. Overall effects of such policy measures cannot be inferred from the outcomes of partial market models of many different partial market models. One of the core issues in economic and policy analysis of agricultural sector is to evaluate changes in crop mix. Farmers tend to specialise in cultivating crops with the highest relative profitability (given some necessary crop rotation and land quality constraints). Changes in crop mix can be analysed only by a model where many individual crops are included and which compete on the given production resources. Thus, a sector level model, if modelled in enough detail, may shed light on many questions which individual product models or highly aggregated GE models are not able to contribute.

Policy analysis using static sector models is performed as follows. First the model is solved for a given base year. The outcome of the model with given base year parameters should correspond to base year supply and demand, as well as product and input prices (if endogenous). The known base year is assumed to correspond to an economic equilibrium represented by the model outcome. Differences between the actual base year and the model outcome are made as small as possible by model validation, i.e. checking the model structure and values of some calibration parameters.

Policy scenario is determined by given values for policy parameters or some other economic or technical parameters in the model. The model is solved for the policy scenario. A new set of supply, demand and prices are obtained as a solution. The outcomes of base run and policy run are compared and conclusions of the effects of alternative agricultural policies or other changes are made based on this comparison. In optimisation approach, marginal values of some constraints can be compared. The method of analysis is comparative statics.

On the basis of implementation and model structure agricultural sector models are traditionally divided in two main categories: econometric models and sector models. The modelling methods have been applied mostly separately, but there are some efforts in combining the methods (Bauer 1988a, p. 17-18). Subsequent chapters discuss positive and negative aspects of both modelling approaches.

3.2.2. Econometric approach

Econometrics is the field of economics that concerns itself with the application of mathematical statistics and the tools of statistical inference to the empirical measurement of relationships postulated in economic theory (Greene 1999, p. 1). The theoretical basis of the econometric approach is most often the same as in optimisation approach: producers are maximising their profits and consumers are maximising their utility under given constraints. The assumption of profit or utility maximisation is at least indirectly embedded in econometric sector models. Explicit optimisation and formulation of a global objective function (which is the case in most optimisation models) are not needed, however, in econometric models. The optimisation conditions can be formulated as a system of econometric simultaneous equations whose parameters are estimated by simultaneous equation methods of standard econometrics.

Duality theory can also be used when formulating the equations, given the assumption that the representative agents (producers and consumers) maximise their profit and utility. An economic equilibrium is assumed, i.e. marginal profits of different products are equalised. The system of equations is solved in such a way that the equilibrium conditions are satisfied (Jensen 1996, p. 23-25).

Econometric equations are quite flexible and different functional forms and sets of different explanatory variables can be tested. One can easily find generally accepted statistical tests and other validation procedures in the literature to base on. Econometric models are also flexible in the sense that they can mimic dynamic patterns by introducing lagged variables. Econometric models can also be truly dynamic and, for example, based on optimality conditions of dynamic optimisation.

Econometrics concerns itself with the use of statistical techniques. This is desirable since the validation of the model to empirical facts is ensured. However, one may have serious estimation problems because of the inconsistency of the parameter estimates due to lagged variables and heteroscedasticity and other problems related to the statistical quality of the data. Data problems may be quite severe for a number of reasons. For example, statistical authorities sometimes change the data definition and acquisition procedures. Consequently, the statistical properties of data may change. Correcting the difficulties in parameter estimation may require considerable efforts and time. Hence, the committment to statistical techniques may be restrictive for a modelling project with limited resources.

In a sector model the supply and demand – with some additional equations needed to establish equilibrium conditions – of many products have to be modelled. Regional perspective and the interactions between the regions and products further increase the dimensions of the model. Econometric modelling of agricultural sector yields a large system of simultaneous equations. First, the identification of such a system has to be ensured. Data preparation, estimation and testing different model structures and specifications, including additional equations needed to satisfy equilibrium conditions, may turn out to be a laborous task. Great care is needed in estimating the parameters of a large system of simultaneous equations. Estimation results and consistency of the parameter estimators may be sensitive to the choice of estimation method (Greene 1999, p. 698-699). In addition, a system of simultaneous equations has to be carefully tested for specification errors and stability. A slightly different specification, like a different functional form or lag structure, may, in a worst case, change the model behaviour considerably. This is due to the complicated estimation procedure of a simultaneous equations system, where a change in the specification of one equation affects the parameter estimates of other equations as well.

The application of systems of econometric equations would be easier in constructing smaller scale partial market models of only one product or a subset of products rather than to include all the complexity of the agricultural sector in one simultaneous equation model. There is likely to be some trade-off between the precision and efficiency of parameter estimates and theoretical consistency of the model due to the simultaneous equation structure. However, one can find some econometric sector models in literature which are applied in many analyses, like Jensen (1996). In Jensen's model some estimated (behavioural) parameters depend on exogenous variables in the model. According to Jensen (1996, p. 65), it was not possible to remedy all statistical problems, like auto-correlation, in the estimation, and some parameter estimates are subject to inefficiency, e.g. imprecision. Estimation of single equations separately was not performed since theoretical consistency was given a higher priority (Jensen 1996, p. 65).

When examining econometric and optimisation models of agricultural sector in the literature (like the ones in Bauer and Henrichsmeyer 1988 or in Heckelei et al. 2001) the concept of economic equilibrium seems to be a prominent feature. In reality, economy, and especially agriculture, may not be in an equilibrium, as assumed in all equilibrium models. This assumption has been seen as problematic both in econometric and optimisation based programming models (see, for example, Jensen 1996, p. 75-76; Apland, Jonasson and Öhlmer 1994, p. 126-127). Some calibration is needed to replicate the base year using the model. Consequently, the assumption of equilibrium rules out any ongoing adjustment process.

Consider, for instance, that a certain production line or crop is significantly more profitable and more competitive relative to imports, but is temporarily affected by exceptionally low EU or world market prices, capital restrictions, or unfavourable weather conditions. Uncertainty of future agricultural policy or a threat of unfavourable policy decisions may also affect short-term production decisions. Suppose the model is calibrated to this kind of disequilibrium base year situation and the alternative policy scenario includes slightly decreased subsidies for this production line. A proper forecast would be that production would still be relatively more profitable than in the other production lines and on the increase, while an analysis based on static equilibrium and calibration would lead to lower activity in that production line.

In short, one can find at least 5 main advantages of econometric models (Bauer 1988a, p. 15): (1) Use of statistical methods for parameter estimation, (2) use of generally accepted calibration and validation procedures, (3) flexibility of specification, like possibility of testing various behavioural assumptions, (4) continuous response to changed exogenous conditions, and (5) integration and test of dynamic lags.

Bauer (1988a, p. 15) also finds considerable disadvantages of econometric approach: (1) Problems in agricultural technology representation and the consideration of internal flows, (2) no or limited use of a priori information, (3) no economic evaluation of fixed factors and internal flows. There may be also (4) serious estimation problems, especially when estimating the parameters of large simultaneous equation systems.

Disadvantages (1) and (3) reported by Bauer (1988a) are no longer as restrictive as they used to be in 1970s and early 1980s since the later econometric literature is rich on dynamic (investment) models considering quasi-fixed factors. Physical linkages and material flows can, at least in principle, also be incorporated in econometric models. What is problematic in the use of econometric techniques in modelling agricultural sector of large dimensions, however, is the difficulty in estimating the parameters of large simultaneous equation systems.

3.2.3. Optimisation models

Optimisation models maximising consumer and producer surplus subject to product balance and resource use constraints (Hazell and Norton 1986, p. 164-168) became increasingly popular in agricultural sector modelling during the 1980s (Bauer and Henrichsmeyer 1988). The optimisation models which simulate competitive markets, most often use cross sectional data or smoothed data from a 2-3 year period as a reference year. In addition to official statistical data, optimisation models can use directly different kinds of technical data, or a priori or expert data. For example, production cost data of different products and other farm level information can be used directly to allocate costs on different products. The data concerning the very latest techniques may not be as rich as the data concerning more mature production technologies. When empirical information is available on fertiliser response trials on crop yields, for example, explicit production functions can be set up which reveal more about the specific properties of, for example, new plant varieties. Such information is usually not available on the new technology, but various a priori information can be used directly in optimisation models. Production technology, support systems, fixed production factors and resource constraints and capacity levels can also be modelled directly. Physical linkages between crop and animal production can be modelled explicitly, together with production quotas and set aside regulations.

Explicit optimisation of producer and consumer surplus produces efficient allocation of consumption and production. Comparing different outcomes when running the optimisation model for different policy scenarios, for example, is consistent with standard economic theory. Comparing results of different policy scenario outcomes with the base year outcome one may make conclusions concerning the effects of agricultural policy on production volume, production allocation, and farm income. One may also analyse the efficiency of different agricultural policy regimes, i.e. impacts of different support payments on farmers income, for example. Results of an optimisation model maximising producer and consumer surplus represent rational economic behaviour. Thus, the results can be expected to forecast future changes in agriculture, given some specific policy parameters.

The optimisation approach offers some ways of analysis which are not easily captured in econometric models, but are theoretically appealing. For example, shadow prices of some explicit physical capacity constraints provide information which may be valuable for decision-makers. Such information can be easily obtained from optimisation models. The duality results are thus an important additional asset of the optimisation approach.

In short, the main advantages of optimisation models of agricultural sector are as follows (Bauer 1988a, p. 15; Bauer and Kasnakoglu 1990, p. 276): (1) Detailed description and representation of agricultural technology, (2) differentiation of the production sectors and explicit consideration of various interactions, (3) use of a priori information for model specification, (4) economic evaluation of the fixed factors and the internal commodity flows, and (5) explicit incorporation on many policy instruments, like physical production limits, foreign trade policies (export and import quotas, tariffs), input subsidies and domestic price policies.

3.3. Problems of optimisation models

Optimisation of consumers and producers surplus has become a very popular approach in agricultural sector modelling since the 1980s. Despite apparent advantages, optimisation models have serious problems and disadvantages which should be recognised and taken into careful analysis in order to make a proper choice between econometric approach and optimisation approach, as well as to find solutions to those problems. There are already procedures to overcome those problems, and some of them are widely used in agricultural sector modelling profession. Many of the attempts to overcome the problems of the optimisation models are based on the idea of applying econometric methods in optimisation models or using econometric methods in estimating parameters of optimisations models (Bauer 1988a, p. 17-18). In other words, there are attempts to combine econometric and optimisation methods in an appropriate way.

Disadvantages of optimisation-based sector models can be summarised as follows (Bauer 1988a, p. 15; Bauer and Kasnakoglu, p. 276): (1) Normative optimisation behaviour due to heavy neo-classical assumptions, (2) aggregation problems, (3) no formalised calibration and validation procedure, (4) discontinuous response to changing exogenous conditions (especially with linear models), and (5) tendency to a strong specialisation in agricultural production. The problems of optimisation models are discussed in more detail below where also some attempts to overcome those problems are discussed.

3.3.1. Unrealistic assumptions

Every model should be evaluated starting with checking the plausibility of the basic assumptions. The assumptions should be reasonably good approximations of the state of affairs in reality. Optimisation approach is strictly based on neoclassical equilibrium theory which assumes perfect rationality, i.e. producers maximise profit and consumers maximise their utility. In the basic standard form of optimisation of consumer and producer surplus, perfect competition is assumed (Hazell and Norton 1986, p. 164-168, 178). Individual producers and consumers are assumed to be unable to influence prices. Given these assumptions one may model the markets of agricultural products as one optimisation model which maximises producer and consumer surplus (Silberberg 1990, p. 492-493).

It is important, however, to recognise that the real agricultural sector in Finland does not behave exactly as an optimisation model because the assumptions do not fully represent reality. For example, farmers may not be able to maximise their profits exactly like a mathematical optimisation algorithm used in solving optimisation models. This is because farmers may not have all the information available needed for explicit profit maximisation. Farmers may also have other objectives in their decision-making in addition to profit maximisation. Since the large population of farmers may have many different kinds of objectives and preferences (like risk aversion, resistance to change because of habits and life style preferences, environmental values, etc.), including them in a sector level model is difficult. Because of other than profit maximising values, the actual aggregate behaviour of farmers may not be as consistent as it is in an optimisation model based on representative farms. Because of many frictions, uncertainty and imperfect information, farmers may not behave as consistently as an mathematical optimisation model, even if they would like to.

In the case of consumers, it may not be possible to explain the aggregate behaviour of consumers using only directly observable economic terms. This is due to trends and fashions which may make consumers respond quite inelastically to price changes of some agricultural products. Consumers have many other products besides agricultural products to choose from. The income of consumers may also have a substantial effect on the demand of certain agricultural products. Thus, it is problematic to model consumer behaviour in a sector-level model. Consumer behaviour implied by a sector level model should not be given too much confidence. Consequently, it may be preferable to treat consumer behaviour and some part of the demand side as exogenous in agricultural sector models.

Perfect competition implies efficient markets, i.e. economic agents trade as long as no trade transaction can improve anybody's profit or utility without lowering the utility or profit of someone else. That is, efficient market outcomes are Pareto-efficient. Markets of agricultural products, however, may have some internal frictions (like inventories or long-term delivery contracts between suppliers and food industry, for example) which prevent immediate response to changed economic and policy environment. By and large, the static nature of optimisation does not allow time-dependent issues like lags in production processes. Rather, it is assumed that consumer and producer surplus is maximised instantaneously, i.e. economic agents are able to respond immediately (or at least quickly enough before any consequent changes in parameters) to changes in market conditions while keeping other parameters constant. In reality, many parameters are changing constantly and simultaneously. On the other hand, producers cannot respond immediately to changes due to fixed production factors. Different agents may have different lags in adapting to changing conditions, while a neo-classical model assumes simultaneous response of all agents. Due to the lag in response to changing conditions, other changes may occur during the lag. Thus, the resulting actual response may depend on the specific sequence of parameter changes, i.e. the policy response may be path-dependent. Consequently, the actual interplay of different economic agents may be different from the model outcome. The lack of dynamics, however, is common for all economic models based on static equilibrium and not only specific for the optimisation approach.

3.3.2. Aggregation problems

Different production lines and regions are usually represented by a single "representative farm". More than one representative farm can be included in the model, at the expense of additional data work and variables in the model. However, serious aggregation problems occur in sector-level optimisation models of agriculture since natural and economic conditions may vary considerably from one location to the other or even from one farm to another (Bauer and Kasnakoglu 1990, p. 276). This is especially the case in Finland with a quite heterogeneous soil quality in relatively small regions or even on individual farms. The history of farms may be very different. Thus, the production planning and production equipment – i.e. production costs – may vary considerably even on farms of the same size.

Given the natural and economic conditions, individual farms may specialise in production which is consistent with their resource constraints and preferences. At the aggregated regional or sector level production appears to be more diversified than in the outcomes of sector-level optimisation models. In addition, the resource rigidities are to some extent relieved in sector-level optimisation models. This is because the use of given total resources in the model is optimised in order to maximise the objective function. This, however, cannot be done very easily in reality. Resources, like some particular types of land, owned by some group of farmers cannot be made easily available to other farmers, as is assumed in sector-level optimisation models.

In a sector model with representative farms and Leontief technology (fixed input-output-relations in production) one is assuming that average cost is also equal to marginal cost. This is rarely the case, however, and marginal behaviour (i.e. changes in the production of different products in response to exogenous changes) cannot be inferred using only aggregate data. If this is attempted, the outcome of a sectoral optimisation model is not likely to match real data or the aggregate results of individual farm models.

The regional aggregation of a sector model should be done in a way that farms and areas with similar production structure and natural conditions (indicated by crop yields) are combined in order to form uniform regions (Hazell and Norton 1986, p. 143-148). Unfortunately, this is not always possible, because aggregate data has been collected from regions which have been established on administrative or some other basis. It may be difficult and costly to derive data with some other regional differentiation. In practice, some aggregation error seems inevitable in modelling agricultural sector. All possible effort, however, has to be made in order to analyse internally homogenous regions or farm types.

3.3.3. Problems in parameter estimation

What is equally problematic in econometric and optimisations models is the estimation of some model parameters. For example, signs of elasticity parameters may depend on the length of time series data used in estimation. This is problematic, since the price elasticity of demand, for example, must be negative in the case of downward sloping demand functions used in optimisation models. In addition, the price elasticity of supply should be positive because of theoretical consistency. In many modelling exercises the model parameters have been set using expert knowledge or adopting parameter estimates from modelling exercises in some other countries (see, for example, Apland and Jonasson 1992, p. A20). This is understandable because of estimation problems or because of the lack of resources available for parameter estimation. Taking parameters directly from other studies and countries, however, should not be accepted as a general practice. In some cases there are obvious cases of misusing the existing parameter estimates (Kasnakoglu 1988, p. 347).

3.3.4. Model validation problems

An optimisation model of the agricultural sector usually has a large number of interdependent equations and variables, often in thousands, so it is not always obvious how the model should be validated. Unlike econometrics, optimisation approach is lacking generally accepted principles, criteria and guidelines for model testing and validation. However, some tests have been used in evaluating the behaviour of optimisation sector models (Hazell and Norton 1986, p. 269-273). For example, one may compare shadow prices of capacity constraints in the model to the actual prices of investment goods, as well as prices and quantities of inputs and products in the model to the actual prices and quantities used and produced in the agricultural sector. The right level of shadow prices and the value of the applied inputs can be considered an indication of the consistency of the model.

However, the validity of agricultural sector models has most often been evaluated by comparing production outcomes of the model to the actual ones. In static equilibrium analysis one thus checks that the production quantities in a base year solution are close to the actual ones. In modelling agricultural sector, i.e. a multitude of products, there is a problem. Production quantities of some commodities are close to actual ones, while production quantities of some other commodities are not. How to evaluate the overall model validity? In the case of small volume products, one may accept even relatively large deviations from the actual production volumes, if the production quantities of high volume products in the model are close to the actual ones. In short, one may accept larger deviations of production quantities from the actual ones of small volume products than in the case of large volume products. Thus, a greater weight may be given to large volume products in evaluating model validity in terms of production volumes.

There is, however, no consensus in the profession of optimisation-based agricultural sector modelling on the statistic to be used in evaluating the fit of the model outcome to the base year data. Some simple measures like mean absolute deviation or percentage absolute deviation have been suggested, as well as Theil index used typically in econometrics (Hazell and Norton 1986, p. 271). In the case of agricultural sector models consisting of many regions one may perform tests on each region separately, but the fit is usually better on the aggregate level than on the regional level. This is understandable, since there is a tendency for overspecialisation of production between regions in an optimisation model (Hazell and Norton 1986, p. 271, Bauer 1988a, p. 15). An additional complication of regional sector models is how to evaluate the model fit when there are considerable differences in fit in different regions. One specification of the model may have a better aggregate fit, while the fit of individual regions may be rather poor. Some alternative specification may have a better fit in individual regions, while aggregate fit may not be that good since the production levels in individual regions may all be slightly biased in the same direction. Thus, one may have difficulties in deciding which model specification to use.

In calibrating an optimisation model some model parameters are changed in such a way that the model outcome is close to actual data in terms of production quantities. The choice of free parameters for calibration is somewhat arbitrary. One may, for example, add some linear or nonlinear terms to the cost function, add risk aversion parameters to the objective function, crop rotation constraints or, in extreme case, simply changing some yield or cost function parameters in an arbitrary way. One may also introduce some ad hoc flexibility constraints, i.e. artificial constraints on the variables in the model. Such calibration methods substantially affect the policy response of the model. However, the implications of such assumptions are usually not very well stated (according to Bauer and Kasnakoglu 1990, p. 276). Worse still, in the absence of generally accepted calibration and validation procedures, and given the limitations of econometric methods in generating the required model parameters, arbitrary and non-explicit adjustments in model parameters may become a routine. Ad hoc parameter or data manipulations hide the actual structural deficiencies of the models. Such manipulations also make the life of models very short and difficult to update. Such modelling and validation practices do not increase the validity of agricultural sector modelling, but deteriorate the trust of policy-makers to model-based economic and policy analysis. As a consequence, even more problematic and less analytical subjective views on policy effects may replace modelling efforts in actual decision-making.

One may have serious difficulties in model calibration: the base year data may not be replicated whatever values are given for calibration parameters. It may be the case that the model is not properly specified, i.e. some important structural dependencies are lacking, and the base year data cannot be replicated by varying the chosen validation parameters. However, difficulties in model calibration may not be an indication of an inadequate or wrong specification. It may be difficult to replicate actual base year data using the model even if the model is properly specified, i.e. all the relevant causal linkages are modelled, and even if some free parameters are available for model validation. This may be due to the fact that the base year does not correspond to an economic equilibrium. These problems, however, are common for both econometric and programming models, and for all models based on static equilibrium reasoning.

3.4. Risk adjusted optimisation models

One characteristic feature of an optimisation model representing the agricultural sector is excessive specialisation between regions (Bauer 1988a, p. 15). The specialisation as such is not a problem – it is a direct consequence of rational profit maximising behaviour which leads to an increase of land allocated for the most profitable crops, for example – but the unrealistic extent of specialisation can be considered a problem. Even if some crop rotational constraints are imposed, optimisation models may produce a land allocation which is in clear contrast to observed cropping patterns. This is the case especially in linear models, i.e. there are linear input-output relations in the model. A certain region may specialise very strongly in producing certain products (possibly only one product is produced if no rotational or other constraints are imposed). Tendency for overspecialisation may also result in overestimates of the value of fixed production factors, like land, irrigation water, etc.

In reality, however, there are a number of frictions which prevent instant or strong specialisation. Such factors may be crop rotation and soil characteristics, other fixed production factors, marketing costs, risk aversion of farmers, etc. Imposing various kinds of restrictions, like upper and lower bounds, on the decision variables may reduce the specialisation, while the tendency to specialisation remains, and the model may still be quite sensitive to even small exogenous changes. Ad hoc restrictions affect the response of the model considerably.

One way to avoid overspecialisation is to bring non-linear terms representing risk averse behaviour into the objective function (Hazell and Norton 1986, p. 216-238). To do this, one needs to assume (in addition to stochastic crop yields and risk averse behaviour of farmers) some price and yield forecasts of farmers. Thus, farmers maximise profits which are dependent on expected values and variances of crop prices and yields, as well as some given risk aversion coefficients. Different price or yield expectation model specifications lead to different equilibria and model behaviour (Hazell and Norton 1986, p. 223-224). Estimating risk aversion coefficients is difficult, especially in price endogenous models with quadratic objective. Ideally, the risk aversion parameters should be formed as suitable aggregates of measured farm-level risk parameters. Nonlinear profit functions, however, cannot be added, and thus the averaging of risk aversion coefficients of individual farmers is only possible in models with linear objective. Consequently, the common procedure in risk-adjusted sector models of agriculture is to use risk aversion parameters which give the best fit to the base year. This, however, is risky, since the base year may not correspond to an economic equilibrium, and the risk aversion parameters may become biased. This, in turn, may result in greatly biased responses to exogenous changes, since the risk aversion coefficients are kept unchanged when solving the policy scenario. Including risk and using the risk coefficients for model calibration may hide serious structural deficiencies of the model. Second, according to Hazell and Norton (1986, p. 238), the selection of best fitting risk aversion parameters led to quite different results depending on the kind of price forecasting behaviour assumed in the model. Without knowledge of how farmers actually form their expectations, the risk aversion parameters remain largely indeterminate (Hazell and Norton 1986, p. 238).

Thus, it is difficult to find an empirical basis for risk aversion coefficients. In practical modelling work, the most appealing criterion for the choice of risk parameters is to force the model into an outcome corresponding to the real situation of the base year. In this case the model works in a satisfactory way only in the short term. There are many random factors, like weather conditions and temporary market disturbances, however, that affect the short-term behaviour of the market. Bread grain areas in Finland, for example, may change up to 50% annually because of changing weather conditions during the sowing period. Even short-term forecasting or policy analysis cannot be easily motivated in that case. One needs to construct a base year of at least 2-year averages of crop areas, yields, and prices in the case of volatile crop areas to be able to use risk-adjusted sector models.

3.5. Positive mathematical programming

Positive mathematical programming (PMP) was created in order to overcome validation problems of optimisation models as well as excessive specialisation in production. While linear or non-linear sector models with few non-linear relationships usually produce drastic and discontinuous responses, the PMP models yield smooth responses to exogenous changes (Howitt 1995, p. 329).

PMP is a method for calibrating models of agricultural production and resource use using non-linear yield or cost functions. The idea of PMP is that a sufficient number of non-linear relationships is added to a model in order to calibrate the model exactly to the base year data.

Many regional models have some non-linear terms in the objective function reflecting endogenous price formation or risk specifications (see, for example, Apland and Jonasson 1992). The addition of non-linear terms improves the diversity of the optimal solution, i.e. a more or less continuous response is obtained when varying some exogenous parameters. The ability to adjust some non-linear parameters in the objective function, typically the risk aversion coefficients, can improve the model calibration. There is, however, often an insufficient number of independent non-linear terms in order to accurately calibrate the model.

The ability to calibrate the model with complete accuracy depends on the number of non-linear terms that can be independently calibrated. Thus, by introducing a sufficient number of non-linearities, PMP procedure calibrates the model exactly to the base year in terms of output, input use, objective function values and dual values on model constraints (Howitt 1995, p. 332). Because non-linear terms in the supply side of the profit function are needed to calibrate a production model, the task of PMP is to define the simplest specification needed in an exact calibration. PMP uses the observed acreage allocations and outputs to infer marginal cost conditions for each observed regional crop allocation. This inference is based on those parameters that are accurately observed, and the usual profit-maximising and concavity assumptions of standard microeconomic theory.

Given a certain commodity price, the modelled optimal production level may exceed the observed level in the base year (or below the base year). At the observed level of production it turns out that – according to the profit maximisation hypothesis – some fraction of production costs, say S, are not covered by the model. These costs can be covered exactly using PMP which proceeds in three steps.

Step 1: A conventional linear or non-linear optimisation model is extended by a set of calibration constraints for the given base year production level X.

Step 2: Shadow prices or calibration constraints are used to derive the non-linear cost function parts which enter into the objective function.

Step 3: The calibration constraints of the first step are removed and it turns out that the model calibrates exactly with the given production levels.

One may use, for example, a quadratic cost function, like $C = aX + 0.5bX^2$ where C is the non-linear part of the total production costs, X is the production activity level and a and b are parameters, in the calibration procedure. The first derivative of this function is $dC/dX = a + bX$ which is equal to S at the point of the observed production level. Assuming that a is zero, parameter $b = S/X'$, where X' is the base year production activity level.

Parameter b can be subjected to econometric analysis to explain changes of the cost structure over space and time. However, the weakness of the approach is that the costs implied in the non-linear cost function cannot be explicitly attributed to specific production factors (Bauer and Kasnakoglu 1986, p. 280-281). Consequently, the model does not contain the actual explanatory variables of the non-linear cost function (activity level itself, which is to be explained, appears in the non-linear cost function, but can hardly be called a proper explanatory variable), whose values may be rather volatile. Thus the derived non-linear cost function may be valid only temporarily. For this reason, it is risky to use the PMP approach in any long-term analysis. The calibrated model may, however, yield quite a reasonable policy response in short-term analysis, if the actual cost factors affecting the non-linear cost function remain unchanged.

One may test between different functional forms of the non-linear cost function. The second derivatives, i.e. curvature properties, greatly affect the response behaviour of the model (Heckelei and Britz 1999, p. 7, 13). Different functional forms have different curvature properties, and the response to exogenous changes may depend crucially on the chosen functional form. Since the specification problem of non-linear cost function parameters become ill-posed, i.e. the number of parameters to be specified is greater than the number of observations, Paris and Howitt (1998) propose a Maximum Entropy (ME) based method to estimate the parameters. ME estimation decreases the need to decide on a priori restrictions on the parameters compared to a traditional econometric approach and allows to employ different functional forms for the objective function. ME estimation also makes it possible to use more than one observation on activity levels into the specification of the parameters, thereby broadening the information base for the specification. Inclusion of more than one observation of each activity level and thus marginal costs (through first derivatives) gives an opportunity to infer curvature properties of the non-linear cost functions from the differences in marginal costs. If there is only one observation the curvature properties are arbitrary and the model behaviour depends on the chosen functional forms. Heckelei and Britz (1999) have developed a method which uses a cross-sectional sample in order to derive changes in marginal cost based on observed differences between regions with different crop rotations. These differences in first derivatives comprise information about the second derivatives, which are relevant for simulation runs.

The PMP approach requires a careful specification of the model structure as well as of the input and output coefficients; otherwise all the errors in model structure or data are incorporated in the non-linear cost function (Bauer and Kasnakoglu 1986, p. 281). In the actual analysis the non-linear cost function is assumed to stay constant. Thus, in the case of inadequate specification of the model or data errors, the resulting response to exogenous changes will be misleading. PMP is obviously not the best choice when explaining structural changes or analysing considerable changes in economic environment. If agricultural technology and the costs of agricultural production, for example, are rapidly changing due to investments, a more structured approach is needed.

According to Howitt (1995), the PMP approach "is developed for the majority of modellers who, for the lack of an empirical justification, data availability, or cost, find that the empirical constraint set does not reproduce base year results". This means that one may stay in a comparative statics framework without the need to know the actual reasons why the optimisation model without calibration does not correspond to the base year equilibrium. Persistence in static framework and using calibration, however, may be deceptive. The non-linear cost functions may not be of permanent nature or stable over time – as is believed in PMP approach: "If the yield response functions calibrated in the PMP method have a basis in regional soil variation and farmer behaviour, then they should be relatively stable over time and can provide additional structural information for policy response" (Howitt 1995, p. 338). Unfortunately, there is no way to test if the non-linear cost function is indeed of permanent nature or if it adds any structural information. Non-linear cost functions incorporate a conglomerate of cost factors which are not identified exactly and attributed to certain variables. Hence, the information contained in the non-linear cost functions can hardly be called structural. PMP is probably not the best way to incorporate structural information and soil variability in a sector model. Structural information used in assessing policy response should be unambiguous and attributable to specific production factors.

PMP approach has become very popular in country-specific agricultural sector modelling in 1990s and has been applied even in relatively large EU-wide models (Heckelei and Britz 2000). The PMP approach has appealing features: one may stay in comparative static framework, which many modellers prefer, and circumvent many difficult problems of structural model specification and validation. One may ask, however, what is the value of the approach in the analysis of structural change or in analysing great changes in economic environment.

3.6. Recursive programming models

3.6.1. Adaptive economics paradigm

The Recursive Programming (RP) models were originally developed in the 1960s as linear programming models that make year-to-year sequential predictions of output over a period of years. This formulation assumes that farmers view the next year's production plan as a deviation from the current farm organisation with a linkage between the current and future plans. This linkage is modelled by constraining production activity levels to a neighbourhood of last year's production activity level, i.e. the upper and lower bounds of the production activity level of the current year depends on the last year's production activity level (Miller 1972, p. 68).

The following, more general definition of recursive programming was given by Day and Cigno (1978, p. 2): "*Recursive Programming represents a general approach to modelling economic behaviour based on the decomposition of large, complex decision problems into sequences of smaller, simpler decision* *problems conditioned by past decisions and observed changes in the decision-maker's environment. Plans and behaviour thus result from a sequence of sub-optimisations that, at any stage in the sequence, may incorporate strategic considerations but which in any case, depend on the past history of the system in a fundamental way. Solutions at each stage satisfy certain optimisation criteria but the sequence as a whole need not: behaviour may be optimal, sub-optimal, or pessimal.*".

This kind of definition or paradigm is in contrast to neo-classical equilibrium methodology, which emphasises rational economic behaviour, profit and utility maximisation, and efficiency of markets. The pioneers of recursive programming approach call their paradigm "adaptive economic theory". The reason for such a theory is the view that the neo-classical economic theory explains poorly, if at all, economic change. It is emphasised that economic change, inter-linked with technological change, exhibits rich patterns of growth, decay, oscillations and waves, whereas neo-classical economics emphasises rationality, profit and utility maximisation and equilibrium. It is seen that neo-classical approach underplays the complexity of technology, overplays the rationality and knowledge of economic agents, and exaggerates the efficiency of markets. Neo-classical approach is, according to adaptive economists, designed for comparative statics: the study how equilibria change and vary with parametric changes in the data of the problem. That is, neo-classical approach is seen as a study of adapted systems which cannot explain how economic change actually occurs, and how exactly new equilibria are found (Day 1978a, p. 235).

An alternative paradigm is needed which considers how economic change, or the process of change, actually occurs in reality. Actual economic development involves the disruption of old equilibria and seeking out of new equilibria. It is seen that the specific time paths toward new equilibria depend on the way decisions are made, and how agents interact to produce aggregate results. Economic development is seen as a dynamic dis-equilibrium process where economic agents are adapting to changed conditions on the basis of what they know and what they are able to do – not necessarily in the optimal way, but optimising sub-optimally, i.e. locally. According to adaptive economics, the "economic man" of neo-classical economics should be replaced with "adaptive man". He is an agent who makes short horizon plans, not because he is irrational, but because of uncertainty and the experience which suggests that caution is often a wise tactic in uncertain and changing economic environment (Day 1978a, p. 235-236).

Adaptive economic theory, as it is called by Day (1978a), attempts to study economic development as a dynamic dis-equilibrium process which may, or may not, converge to a certain equilibrium. In short, adaptive economic theory is a theory of partial economising or optimisation with feedback that describes economic behaviour in dis-equilibrium or, possibly, though unlikely, in equilibrium. In the adaptive economics paradigm, one tries to understand and model the explicit mechanisms how economic development actually occurs. Recursive programming models are seen as appropriate tools in modelling economic development.

3.6.2. The concept of cautious sub-optimising

The adaptive sub-optimising of an adaptive man as a goal-directed behaviour consists of learning and search algorithms. It involves making locally best choices on the basis of approximations of environmental feedback. These, in turn, are obtained from estimates of the current situation and past feedback. In other words, the behaviour of an adaptive man is characterised – not by a mathematical optimisation machine – but by a sequence of local optimisations with feedback. The sequence of successive optimisations is called recursive programming.

The sub-optimising with feedback may include long-term strategic decisions, but may also use one-period optimisation as the basis of choice without considering long-run trajectories based on an explicit representation of environmental feedback. This can be called myopic behaviour which does not account for feedback in the distant future. If the decision makers make long-term strategic decisions, they often account for them in a rule-of-thumb manner by introducing constraints on current choices and modifying anticipated payoffs. Even strategic decisions, however, are not made once and for all, but they are re-evaluated and reconstituted as time passes (Day and Groves 1975, p. 23) According to Day (1978, p. 235-236), the reason for sub-optimal decisions is that "*the task of estimating competitors' behaviours far exceeds his (an economic agent's) computational ability, just as it far exceeds the capacity of the largest and most sophisticated economic modelling center*". In other words, rationality is bounded by limited perception, logical power and economic capacity. Because of imperfect information the choice set of risk aversing economic agent is limited to a "safe-enough" subset of possible alternatives dictated by the sense of caution (Day 1975, p. 26-27).

The behaviour of an "adaptive man" is not characterised by an optimal control or a dynamic optimisation model, but by sequences of optimisations with feedback, that is, by a recursive programming model which represents the essentially tactical nature of adaptive man's struggle with reality.

3.6.3. Estimating and evaluating recursive programming models

Recursive programming models, when applied to agricultural sector modelling, are actually sequences of standard optimisation sector models. Data issues and validation problems of such models have already been discussed in Chapter

3.2.3. Recursive programming models suffer from all the problems typical for optimisation models. The dynamic specification may make these problems even more severe since even small errors may accumulate to great errors over time.

Day and Cigno (1978, p. 40) present some principles on acquiring parameter estimates for recursive programming models. The parameters can be divided into two main categories: directly estimatable parameters and indirectly estimatable parameters.

Directly estimatable parameters are those which are publicly available in official statistics or publications, or can be acquired from experts with little effort. Such data can be experimental data from scientific experiments, technical coefficients, engineering data, empirical input-output-data, firm level data calculated in firms or in governmental institutions. Technical coefficients and engineering data may include new technological innovations, like new production methods with distinct input-output-relations. Such data can be acquired from firms selling and promoting the new technology.

Indirectly estimatable parameters are those parameters which need to be inferred from the behaviour of the observed (real) system to be modelled. Statistical techniques and inference can be used in this estimation (Day and Cigno 1978, p. 43-44).

Despite all efforts spent on direct or indirect parameter estimation no satisfactory procedures may be found for deriving estimates of some parameters. According to Day and Cigno (1978, p. 45), such parameters can be simply guessed using some simple arguments. Later one can perform some sensitivity analysis concerning the guessed parameter values.

What is not explicitly stated by Day and Cigno, however, is that some unknown parameters of optimisation models are often used in model calibration. In a dynamic framework the validation may be more difficult, since adjusting one single parameter value may not be enough to improve the model behaviour at all time points. The assumption of dis-equilibrium, however, circumvents the problems of calibrating the model exactly to base year data. While starting the simulation from a certain base year, flexibility constraints restrict the outcome of the model reasonably close to the base year data. In later ex-post years, however, the simulation behaviour of the model may not track the observed time series despite the flexibility constraints. One should not replicate the observed time series by adjusting the flexibility constraints, however. The flexibility constraints should remain constant throughout the simulation period and represent either the statistically derived possibilities of change or well-based technical, biological or other constraints. If used for calibration the meaning of the flexibility constraints become quite ambiguous.

There are two potential reasons for the divergence of the simulation behaviour of the model from the observed time series. The model may be inadequate to explain the reactions in the sector and thus need structural re-specification.

There may be also some random shocks (like exceptional weather conditions or food scandals propagated in the media which affect agriculture) not incorporated in the model, which cause the difference between the reality and the model results. In the case of exceptional weather conditions, some temporary adjustment of crop yields, for example, could be used to make the model behave better in the early ex post phase of the simulation.

Some unknown parameters of the model, if any, can also be used in calibration. This is appropriate if all but few parameters are empirically well-based. Hence, the residual of the actual sector behaviour not tracked by the model can be assumed to result from the unknown parameters. These parameters, however, should have a sound interpretation and logic. For example, there may be structures in the model representing certain behavioural rules, sunk cost behaviour or investment functions whose all parameters cannot be estimated because of the lack of data. If there are good reasons to believe that the unexplained behaviour of farmers result from a particular factor, then the unknown parameter values can be adjusted in order to calibrate the model close to the observed time series. One should be careful, however, not to include all random fluctuation in the model parameters. Careful judgement is needed how close the model outcome has to be to the actual data values.

3.6.4. Estimating the flexibility constraints in recursive programming

One way to incorporate the principle of cautious sub-optimising in recursive programming models is to introduce flexibility constraints into a mathematical programming model. Such constraints are important in representing a conglomerate of forces which lead to sluggish supply response of farmers. However, one may clearly identify some of the most prominent factors causing quite inelastic short-term reactions to changed economic conditions. Such factors may be biological and technical lags in agriculture, and possibly risk averse decision-making of farmers.

The flexibility constraints may influence the supply response considerably in the medium and long term and hence must not be arbitrary. Miller (1972) presents some possible procedures in determining the values of flexibility constraints. They can be summarised as follows:

1. Informed judgements whereby people who are familiar with the situation estimate the maximum changes that may be expected.
2. Flexibility coefficients estimated as averages (means) of positive and negative percentage changes in the past.
3. Flexibility coefficients as described in (2) plus (minus) the standard deviation of the respective increasing (decreasing) percentages.

4. Flexibility coefficients defined as the maximum of historical percentage changes.
5. Estimation of flexibility coefficients by the simple model

   $$X_t = bX_{t-1} \tag{3.1}$$

   where X_t is the activity level and parameter *b* represent the flexibility constraints to be estimated.
6. Estimation of flexibility constraints by more general models, like

   $$X_t = a + bX_{t-1} + c_1Z_1 + \cdots + c_pZ_p \tag{3.2}$$

   where Z_1 …. Z_p represent some variables influencing the change in variable X_t.
7. Least squares estimates of flexibility coefficients adjusted by standard errors. These standard errors may be either the standard error of the regression coefficient *b*, or standard error of the estimate of X_t.
8. Use of a single least squares equation to derive both upper and lower bounds. In this case, a least squares point estimate of X_t plus and minus some function of the standard error serves as upper and lower bounds. This procedure defines the allowable range around a forecast of year t.
9. Analysis of the discrepancy between the optimum and the actual response.
10. Basing the flexibility constraints on their shadow values (given some initial estimates).

As a generalisation, statistically derived flexibility constraints are made up of two components: a base that is in some respect a prediction of the time series (for which the upper and lower bounds are calculated), and the bounds around this base (the actual flexibility constraints). A potential bias consists thus of the bias of the base and the bias of the magnitude of the upper and lower bounds around the base.

Using statistical techniques in deriving flexibility constraints assumes implicitly that no great changes or revolutions occur in the actual process of the time series, i.e. the stochastic properties of the time series of the stochastic variable will remain constant. In normal cases, without revolutionary changes in the economic environment, this may be a reasonable assumption. However, in the case of significant economic and policy changes, one may not reasonably assume constant stochastic properties of the production time series. One should also recognise that there is some uncertainty concerning the econometrically estimated parameters. The given standard errors produced by the chosen estimating procedure may not be correct, for example, if the estimator is inconsistent. In general, an explicit sensitivity analysis concerning the numerical values of the flexibility constraints may also be required when using econometric methods in deriving the flexibility constraints.

One may conclude that the use of flexibility constraints can be considered both a disadvantage and an advantage in recursive programming. On the one hand, the flexibility constraints are a source of uncertainty to be taken into account by the modeller. The flexibility constraints may also make the RP models vulnerable to the objections of arbitrariness of the overall model results. On the other hand, the use of flexibility constraints can increase the reliability of the projections by ruling out evidently false outcomes. The flexibility constraints may also make the modeller more aware of the uncertainties relating to the overall model. All parameter values, even if they are estimated by the most sophisticated econometric methods, are always somewhat uncertain. The explicit use of flexibility constraints makes it possible to perform various kinds of sensitivity analysis. One may derive robust results, or show the sensitivity of the economic performance to the values of the flexibility constraints. If the flexibility constraints can be linked to particular technical, biological or behavioural constraints influencing the economic performance of economic agents, such sensitivity analysis may provide valuable information for economic agents and policy-makers.

3.7. Other optimisation-based sector modelling approaches

3.7.1. Joint crop activities

In traditional optimisation-based sector models production activities are usually single product activities, which causes the problem of unrealistic overspecialisation and unrealistic jumps in supply response. The combination of average technologies and simplified resource constraints, together with linear input-output relations, lead to overly abrupt supply responses.

McCarl (1982) proposes a method where joint crop activities are used instead of single independent crop activities. In the McCarl's approach the specialised crop rotations have an empirically derived yield penalty. McCarl's approach uses solutions from detailed firm-level models or time series of observed aggregate production levels to be able to account for relationships in yields between crops. In practice, time series data of regional crop production levels can be used to represent a range of technically feasible production patterns. Implicitly, technical conditions, constraints due to soil types, and crop rotations prevail in the data (and so do the effects of exceptional weather conditions which smooth out if long time series are used). Based on this data alternative joint crop production activities are constructed, which are used instead of crop activities of individual crops. The joint crop activities are constructed in such a way that the yield is decreasing if the share of the crop of the total crop area is increasing. Thus there is a penalty associated with specialisation in crop production and the adjustment to changes in relative crop prices is less extreme. The model would choose the optimal joint production activity based on the relative prices and yields of the crops. The production response is thus dependent on the available joint crop activities.

Apland and Jonasson (1992, p. 12-13, 17, 20) apply this procedure by taking simply the regional observed cropping patterns (i.e. crop areas allocated for individual crops) as joint crop activities. Apland and Jonasson also include artificial joint production patterns in order to have a wider range of crop pattern variety. However, making some rather extreme alternatives on ad hoc basis is not consistent with the idea of using time series data as a basis for the joint crop activities. Furthermore, when adopting the observed cross sectional data of some particular years as joint product activities, the relationship between the yields and specialisation of crop cultivation is hard to justify because of changing weather conditions. In other words, different yield levels in different years may not be caused by different cropping patterns but by different weather conditions. The cropping areas themselves are influenced by the weather conditions during the sowing period.

One serious disadvantage of the practical application of Apland and Jonasson (1992) is that input requirements are assumed identical for all joint crop products. Thus, unlike the yields, the input requirement per hectare is assumed independent of the activity. According to Apland and Jonasson (1992, p. 17), this assumption can be easily relaxed. When defining the aggregate input use, like fertilisation, per each joint crop activity only, it is impossible to incorporate fertiliser response which is distinct for each crop. Thus the input use is insensitive to product and input prices. If different input requirements were defined for each joint crop activity, some link would be established between the use of input, and input and product prices. However, penalising the most profitable crops, which tend to expand by area, by decreasing yields, implies that increasing product prices result in lower yields while lower prices result in higher crop yields. Nevertheless, when considering fertiliser response functions, the increase of fertilisation and yields (due to more favourable price relation between fertiliser and product prices) may more than offset the yields degrading effect of expanding the production to less favourable soil types. Hence, there are many problems in adopting the approach suggested by McCarl and applied by Apland and Jonasson.

An alternative to time series data in constructing joint crop activities is to use representative farm level models with detailed technical, such as crop rotation and soil type constraints which lead to diversified crop patterns. Optimal crop mixes under a variety of product prices can be used in constructing aggregate joint product activities for the price endogenous sector model. According to Jonasson and Apland (1997, p. 110-111), consistent empirical data for this approach may be lacking, and the cost of doing the necessary firm-level modelling may often be prohibitive. For example, in Sweden crop rotations may include 10 to 20 potential crops. If only some of the alternatives are included, the result is an inflexible model. Thus the application of the proposal based on joint product activities presented by McCarl is difficult.

3.7.2. Joint farm activities

Jonasson and Apland (1997), when discussing some other attempts to overcome the problems of overspecialisation and abrupt supply response, are not satisfied with the offered solutions. For example, they conclude that PMP (positive mathematical programming) does not actually solve the problems, but is a method to compensate for a poor technology representation, and the model is only valid within a limited range from the base solution for which it is calibrated (Jonasson and Apland 1997, p. 111).

Jonasson and Apland (1997) use full-scale farm activities instead of joint crop activities proposed by McCarl (1982). In the approach suggested by Jonasson and Apland (1997) the basic idea is similar to that of McCarl, but it is more general in terms of input use and efficiency. The joint crop activities are replaced by full-scale farms which may include both crop and livestock activities as a joint activity. Due to differences in resource endowments and measured efficiency, separate farm groups have been established. Furthermore, the farms operate on the boundary or in the interior of the efficient technology set, i.e. they are not always at the efficient frontier of the technology set. Using a large set of farm-level data as an input, farms are divided into categories based on their efficiency. The measure of efficiency is found by solving a linear programming model maximising profit and then relating the actual, real revenue, to the optimal revenue. The farms are grouped on the basis of their efficiency measures.

The farm groups and their efficiency measures are incorporated in a standard static sector model in straightforward way: The product specific production activities, like hectares of crops and numbers of animals, are replaced by joint farm-level production activities. Given a fixed number of farms in each group, the endogenous variable determining the supply is the level of joint activity in each farm group. Resource constraints apply to each farm group separately. Thus farms cannot use the resources of the farms in other groups. Hence, the resources are not used in the optimal way in maximising producer and consumer surplus as is the case in traditional optimisation-based sector models. The efficiency measures derived from empirical farm level data are also different in different farm groups, and the production costs are different in different farm groups. Including several farm groups one thus has several marginal costs in each region. This, in turn, results in a smooth supply response to price changes. According to the results of Jonasson and Apland, the base year data could be replicated more accurately than the traditional model of Apland and Jonasson (1992).

The weakness of the approach is, however, insensitivity to extreme price changes. According to the results computed by Jonassan and Apland (1997), total grain production is almost inelastic at extremely low prices. This is due to the fact that there were few, if any, cases in the sample where milk, beef, pork or other products could be produced without grain. Thus the farm-based joint production activities result in inflexibility. As concluded by Jonasson and Apland, the model is applicable only in a limited range of changes in prices and policies. Hence, one may ask, what is the benefit of the proposed approach compared to PMP, which was also concluded to be valid only in a limited range from the base year solution. Considering the considerable work and effort devoted to deriving efficiency measures and constructing farm groups, the benefit of the approach is not clear. The same kind of results, like smooth supply response and validity close to the base year, possibly without insensitivity to extreme prices, could have been computed quite inexpensively by PMP, with an additional benefit of exact base year calibration, which is already routine in many modelling applications.

The advantage of including many farm types is, however, that the shadow values of the resource constraints of different farm groups offer information on the pressures for structural changes. The fixed number of farms and fixed resources in each group, as well as the exclusion of fixed costs, make the model appropriate only for short-term analyses. Resource fixity may not always be an appropriate assumption, since land and machinery, and even buildings, can be rented. The principle of resource fixity on the farm group level may be an exaggeration. Jonasson and Apland conclude that a comprehensive dynamic model is needed in order to predict the course of structural change.

3.7.3. Dynamic systems analysis approach

An example of an optimisation model in a dynamic framework is presented by Bauer (1988b). The basic assumption behind most of the optimisation approaches discussed above is that profit maximisation is an adequate description of farmers' behaviour and that the production costs estimated are incomplete and insufficient. By contrast, Bauer assumes that static profit maximisation is not adequate to explain the economic behaviour of farmers, and that production costs are correctly estimated. The model constructed by Bauer does not assume an economic equilibrium in each period of time. Rather, it is argued that for a number of reasons, like dynamic relations and heterogeneous behavioural rules, the situation in agriculture is dis-equilibrium which requires endogenous adjustment over time. Dynamics and sunk costs, for example, prevent instantaneous adjustment. A set of shadow prices of the resource constraints is an incentive for adjustment. On the basis of shadow prices, lagged variables and information, some behavioural rules are constructed and estimated. Thus Bauer has combined optimisation and econometric approaches. Some technological change is incorporated in input-output-coefficients as well as in parameters of certain production functions. There may be alternative production technologies available, and the adoption of new technologies is influenced by economic conditions and accumulated and available capital for investment. Such a comprehensive and large dynamic model using shadow prices and lagged variables as explanatory variables is, according to Bauer (1988b, p. 330), able to explain significant changes and turning points of economic variables. Short-term effects of economic changes may be very different from the long-term effects.

A systems analysis approach first identifies the relevant policy questions, outlines the sector and policy systems themselves, clarifies the relevant economic variables and linkages, builds the specific system components, and links them. Without trying to keep in the domain of some individual model types, several model types and relevant approaches to specific problems can be used. There are various single approaches which are preferable to a specific sector system component. Different sub-units will be build to describe the most relevant mechanisms in the sector. Sub-units can be changed if appropriate without the need to revise the model structure or a need to re-estimate all model parameters. This kind of flexible framework makes it possible test and experiment different behavioural rules, lag structures and causal linkages.

According to Bauer (1988a, p. 19) such a system analysis approach should be seen as a global research plan. The specific task of each sub-unit can be finalised and the available methodologies and experiences can be reviewed in a comprehensive manner. Continuous updating and revision is necessary. Additional empirical and methodological research is needed to test alternative assumptions and specifications to complete or improve certain model components and integrate them into the overall system.

3.8. Conflict between theory and practice in agricultural production economics

The emphasis of most agricultural sector models is in the modelling of supply of agricultural commodities. The discussion concerning risk adjusted optimisation models and positive mathematical programming made it clear that the main dilemma of optimisation models is how to explain the actual production data using profit maximising representative firms, i.e. production theory. This problem is of more general nature and concerns not only the optimisation approach of building sector models.

Babcock (1999), Just and Pope (1999) and Love (1999) discuss conflicts between theory and practice of agricultural production economics. Love (1999) discusses testing the propositions of the theory of the firm. Profit maximising or cost minimising behaviour impose certain regularity conditions that can be tested to determine if the assumed behavioural objective is consistent with the actual data of economic behaviour. As a general practice in production economics, parameters of flexible functional forms are estimated using either firm-level or market-level data, and theory-implied parameter restrictions are tested. If theoretical conditions are not rejected, estimated functions are concluded to be consistent with profit-maximisation or cost-minimisation behaviour subject to a set of postulates on technology, i.e. there exists a continuous, concave, and monotonic production function.

According to Love, one explanation for frequent rejection of some propositions of firm behaviour (like homogeneity, symmetry, and curvature properties) is that commonly used testing procedures are biased, and thus some regularity conditions are inappropriately rejected in empirical analyses. Love proposes some practical solutions to improve the tests, but he concludes that testing such hypotheses of economic behaviour is actually testing joint hypotheses. Model specification assumptions include a behavioural objective and relevant constraints. Producers may minimise cost or maximise profit or expected utility. Relevant constraints on optimising behaviour include those relating to capital, family labour availability, financial constraints, dynamic adjustments of quasi-fixed capital, and human capital. Any mis-specification may be a cause of inconsistent parameter estimates.

Just and Pope present several reasons for incongruence between agricultural production theory and accumulated empirical evidence concerning farmers' economic behaviour. Most of the explanations offered by Just and Pope refer to heterogeneity of farms and aggregation errors. Possible explanations offered are temporal aggregation bias with discrete measurement (even though production is continuous in time), heterogeneous financial structure of the farms (which implies that farm's profit maximisation or cost minimisation problem must be corrected to reflect credit availability), and price heterogeneity (prices which are subject to temporal aggregation are not the same for all farms because of a number of reasons).

In addition to these explanations Just and Pope discuss "failure of profit maximisation due to tastes and preferences", "failure of profit maximisation because of risk aversion", as well as "dynamic reality with static modelling", i.e. problems of addressing inherently dynamic production processes in a static framework. These latter explanations are more fundamental by nature than the aggregation or heterogeneity explanations which can be handled, in principle, by proper data acquisition procedures and more appropriate aggregation. These last three explanations refer directly to the behavioural principles of production theory as well as neo-classical theory in general. Just and Pope conclude that some aggregation errors can be overcome because “reporting independent data distributions for capital, prices, government control, and many determinants of technology (e.g. land quality) is possible with little additional public expense”. However, obtaining data of the distributution of technology and other farm-level characteristics is difficult. In addition, standard properties of production theory can be expected to fail even at the level of individual farms. According to Just and Pope, this is because of imperfect capital markets, risk aversion, temporal aggregation, and errors in measurement. In such cases the failure of production theory to explain the aggregate-level production data is not surprising, and, according to Just and Pope, “requires better firm modelling” (p. 718). Just and Pope do not discuss, however, how to model firms better than the standard practice based on production theory.

Babcock sums up the notions of Love, and Just and Pope. Babcock presents and discusses three stylised facts of US agriculture:

1. Costs vary significantly between firms. The empirical evidence from firm-level cost data suggests the existence of significant cost differences between farms producing the same products. Such a heterogeneity in costs, in turn, suggests that firms are not profit maximisers (this possibility is ruled out in production theory *a priori*, however), or that the cost differences are due to heterogeneous physical and human capital, i.e. skills of farmers, and heterogeneous production techniques.

2. Agricultural production is stochastic and dynamic. Previous input decisions affect both the marginal product of later input as well as production output. All the decisions are conditional on the earlier decisions.

3. Price heterogeneity is increasingly important in agriculture. For example, large-scale producers may be paid higher prices for their products than is paid to small-scale producers. Differences in quality of the products may also result in price heterogeneity. Different prices for different producers can also be explained by contracts between food industry and farmers.

According to Babcock, one should not expect the production theory models to support standard properties agricultural supply functions or to provide robust parameter estimates either, unless one cannot obtain higher order moments than simple means of the distributions of capital and technology across firms. Given this, Love’s suggestion to use more robust and appropriate testing procedures can be discarded. According to Just and Pope, the problem of heterogeneity cannot be easily overcome empirically, i.e. deriving data distributions and explicitly accounting for heterogeneity of many parameters is a formidable task. According to Babcock, farmers do the best they can to maximise profits, given their education and constraints on land, finances, and technology availability. But one should not expect the behaviour of farmers to be identical to that implied by production theory and to satisfy Hotelling's lemma, i.e. the supply function of a firm is a first derivative of the profit function relative to price (Varian 1992, p. 43). According to Babcock, one should accept this state of affairs, even though there are agricultural economists who are reluctant to accept this.

The short-run remedy for such problems, according to Babcock, is to use flexible functional forms, i.e. forms that can attain the level, as well as first and second derivatives of an underlying true function at some value of parameters. Such functional forms can, according to Babcock, approximate almost any data-generating function and are easy to estimate, interpret, and incorporate into simulation models. The application of such functions could eliminate the frequent problems with the assumed regularity conditions.

The long-run lesson presented by Babcock is that one "needs to take a fresh look at the physical, financial, and technological environment that firms actually operate in". One can then construct models that incorporate this reality. Babcock does not discuss the issue any further. Such a view, however, inevitably means that much more constraints have to be imposed on profit maximisation models representing individual firms or representative firms. Inclusion of many constraints and deriving their parameter values from empirical data may be a formidable task even at the level of an individual firm. Accounting for many possible constraints and sources of heterogeneity at the sector level is even more complicated. Such a global research plan increases the number of constraints drastically to ensure the realism of the supply response.

The same kind of reasoning emphasising the need for more explicit modelling of heterogeneity, dynamics and risk aversion can be found in the domain of agricultural sector modelling. Bauer (1988a, p. 19-20) presents some basic fields of research:

1. An adequate representation of agricultural technology. In contrast to conventional procedures and certain assumptions, basic interdisciplinary research has to be undertaken in order to increase our knowledge about adequate agricultural technology concepts and empirical findings. Induced technical change, innovations and relationships between applied technology and environmental damage, for example, should be detailed and included to models in such a way that these policy issues can be incorporated.

2. Interdisciplinary research, together with sociologists and psychologists, should be conducted in clarifying farmers' objectives and behaviour. Based upon the outcome of such studies it should be possible (according to Bauer 1988a) to formulate generalised hypothesis about behavioural rules and decision-relevant information. The farm household model may serve as a starting point. Additionally, the influence of socio-economic behavioural variation on the behaviour of farmers should be considered.

3. The dynamic aspects of agricultural sector development should be modelled more explicitly including a systematic formulation of the dynamic linkages in various areas of the sector system. Such a comprehensive dynamic system may help to formulate adequate technological and behavioural assumptions.

These suggestions are very similar to those presented by Babcock. This is understandable since production theory is being applied in agricultural sector modelling.

There is a large number of studies that support the importance of dynamics in supply models and the existence of adjustment costs. Let us briefly consider the findings of Buhr and Kim (1997). Buhr and Kim analysed the dynamic adjustment of US beef industry using a model maximising the net present value of profits, given the initial stock of fixed and quasi-fixed inputs. The US beef industry has historically experienced difficulties in adjusting to short term changes in market conditions. This, according to Buhr and Kim, is caused by long biological lags of production, limited storage capacity and significant adjustment costs in processing and wholesaling because of capacity constraints. In estimating the model parameters, Buhr and Kim were able to reject the hypothesis of independent instantaneous adjustment, which confirms the existence of adjustment costs. The results of the analysis demonstrate that all sub-sectors of beef industry exhibit significant adjustment costs due to either biological lags or capital fixity.

Given the empirical evidence presented by many agricultural economists, the implications of heterogeneity, dynamics and risk aversion should be given more weight in constructing sector models of agriculture.

4. The preferred modelling approach

In the following the selection of the model type is motivated by first ruling out the approaches which apparently do not provide answers to posed questions, i.e. do not meet the selection criteria presented in Chapter 1. One also needs to rule out the approaches whose basic assumptions are too abstract from the reality, or from the stylised facts of Finnish agriculture (MTTL 2000). After ruling out the obviously inappropriate modelling techniques and model types, the final selection of the model type is made by comparing the advantages and disadvantages of the remaining alternative approaches. It turns out that the final model selection, in this particular case, is relatively straightforward.

The model has to be fairly large and complex because all the main production lines have to be modelled in detail in all support regions of agriculture: A, B BS, C1, C2, C2P, C3 and C4.

It is evident that the model must be inherently dynamic in order to meet objectives 1-7 presented in Chapter 1. Static equilibrium models assume simultaneous adjustment of all agents and rule out dynamic and gradual adjustment processes which are the most relevant in analysing the adjustment of Finnish agriculture into the EU.

Adjustment of Finnish agriculture to the Common Agricultural Policy (CAP) takes a long time. Furthermore, CAP is subject to considerable changes because of Agenda 2000 implemented during 2000-2003. Further changes in CAP after 2002 are already under speculation. An investment program is in progress in order to increase the efficiency of agricultural production in Finland. Thus, the reasons why the Finnish agriculture was not in equilibrium in the late 1990s are quite different to those why the Finnish agriculture was not in equilibrium in the early 1990s. There has been considerable structural changes in both agricultural production and in food industry since 1995 and the early 1990s. Prices and supports have been constantly changing since 1995. During 1991-1995 there were very few agricultural investments because of the uncertainty of future prices and supports. There is no reason to believe that any year in the 1990s would represent an equilibrium where all agents have adjusted to the particular prices and supports of that year. On the contrary, the ongoing structural change reflects the fact that many farmers are trying to change their production systems, which were build under a very different policy regime, in order to achieve a better economic performance under the CAP.

Policy changes, like Agenda 2000, are themselves gradual and do not take place simultaneously. Thus the policy effects are also time-dependent. Dynamics and lags in adjustment to policy changes, as well as long-term development of agricultural production, are very central issues to be studied. In the case of modelling agricultural markets in Finland there are many aspects which make it problematic to apply static optimisation models or any neo-classical equilibrium-based methodology where little can be said about the timing of the equilibrium outcome of the model. Decision-makers are more interested to see dated results rather than comparisons between some theoretical steady-state equilibria which cannot be dated to some particular year.

One has to analyse the plausibility of the assumptions employed in dynamic economic models and rule out ones with obviously inappropriate assumptions or methodology concerning the particular case of the Finnish agriculture.

Dynamic economic models can be roughly divided in two main groups, econometric models and optimisation models. There are also econometric models that can be considered optimisation models with unknown parameters, i.e. econometric and optimisation procedures are combined in order to solve optimisation models with unknown parameters. Optimisation models of market behaviour in a dynamic setting can be divided into two main groups, (1) recursive programming models with assumed dis-equilibrium (presented in Chapter 3.6), and (2) programming models which calculate sequences of equilibria or equilibrium movements.

There are dynamic optimisation models which maximise net present value of future profits and incorporate explicit strategic considerations. These models are mostly used in modelling strategic behaviour of individual firms. However, at the aggregate level modelling of agricultural sector dynamic optimisation models based on representative farms are rarely used, if at all. There is little theoretical motivation or empirical evidence that an entire aggregate agricultural sector or some individual lines of production consisting of many farmers would make joint inter-temporal strategic decisions in order to maximise joint net expected profits. It is problematic to model aggregate-level economic dynamics on the basis of representative firms whose strategic decisions would represent the entire sector. This is due to the diversity of firms in many respects, not least in terms of production costs. There is a considerable diversity in production costs on Finnish farms (Riepponen 1998). Strategic decisions of different firms are likely to be very different.

Thus the final choice of a model type is made between econometric modelling and recursive programming of successive equilibrium or dis-equilibrium states.

As already summarised in Chapter 3, the econometric modelling approach has a number of advantages and should not be ruled out a priori. The disadvantages, however, outweigh the advantages in this particular case. A very specific problem in the use of econometric approach in analysing Finnish agriculture would be that the economic environment changed drastically when Finland joined EU 1995. It is problematic to use parameter estimates estimated using the data from the era of the old policy regime, in making economic and policy analysis in the new and very different policy regime.

Hence, there are two main reasons why the econometric approach is discarded. First, estimating model parameters using data from the 1990s and using them when analysing the effects of future policy options is likely to result in misleading results. Second, the number of dimensions of the sector model to be constructed is very large since there are many products, inputs and regions with corresponding product balance and other constraints. As already discussed in Chapter 3, estimation of parameters of large systems of simultaneous equations, particularly if embedded with dynamic lags, is very difficult.

It is stated by various authors that incorporation of internal material flows (like crops used in feeding cattle), specific representation of multiple input agricultural technology, certain policy measures directly linked to physical production factors, like physical production quotas, base area of CAP support, as well as set-aside rates, are best to be modelled in optimisation framework (Bauer 1988a, Bauer and Kasnakoglu 1990, p. 275-276). When physical production factors (number of animals, hectares of crops, kilos of feed) appear explicitly in the model, the inclusion of environmental indicators into an optimisation model is quite straightforward.

Thus the econometric models are discarded and the remaining methodological choice is a dynamic model based on optimisation. The choice between the two alternative dynamic models, equilibrium or dis-equilibrium, is clear since the equilibrium is not a plausible assumption. Hence, the methodology to be used is recursive programming in a dis-equilibrium setting. It is appropriate to start the dynamic simulation in the year of EU integration because when starting earlier than 1995 one should model two very different and complex policy regimes.

Any of the recursive programming (RP) models presented in Day and Cigno (1978), for example, would not meet the criteria given in Chapter 1. One needs to add many additional features into simple RP models, such as foreign trade, technical change, agricultural policy measures, like supports, set aside regulations and production quotas. Specific techniques and assumptions have to be used in modelling each of these aspects.

However, there are also many problems in recursive programming models which need to be solved. These problems are mostly related to the estimation of model parameters as well as the validation of the model. These issues will be discussed in Chapters 6 and 7.

5. Theoretical foundations of the chosen modelling approach

The basic concepts and assumptions of the theoretical basis of the DREMFIA model are discussed in this chapter. Especially, the arguments favouring the recursive programming approach are presented and motivated, followed by a discussion of the adaptive economics paradigm used in the model. Inclusion of the extended model with endogenous technology diffusion is a small step in the direction of evolutionary economics.

Economic models are always based on a set of assumptions and theoretical reasoning how economic agents and economy as a whole work. The outcomes of the model should be evaluated on the basis of the plausibility and realism of the initial assumptions of theory underlying the model. This applies to the models based on the traditional neo-classical theory as well as alternative approaches. For this reason, the most central themes and assumptions of the DREMFIA model are discussed and evaluated in this chapter. Some assumptions require considerable discussion and well-established arguments. Due to the numerous and serious difficulties encountered with the recent agricultural sector models of agriculture (discussed in Chapter 3), a quite different philosophy and mix of assumptions have been adopted in this study. The DREMFIA model is based on a consistent mixture of ideas represented by neo-classical and adaptive economics schools of thought. The sub-model of endogenous technology diffusion is consistent to evolutionary economics paradigm (represented by Nelson 1995, for example), but the DREMFIA model as a whole is an application of adaptive economics paradigm and cannot be called an evolutionary model. This chapter tries to evaluate the relative merits and disadvantages of different schools of thought, and select the most appropriate and still consistent combination of assumptions to be used when constructing an agricultural sector model of Finnish agriculture.

5.1. General hypothesis

One of the basic motivations to build mathematical models of the real world is that a model is more than a simple sum of its basic components. It is essentially the interaction between the components, like economic agents, which constitute the overall setting of a model. Thus one has two basic dimensions in evaluating the basic setup of a model.

First, each of the specific assumptions concerning the individual components or agents in the models should not be too far from reality. What is “too far” depends on the context and the questions to be answered using the models. In some cases models based on perfect competition and static equilibrium may be valuable. A static equilibrium model may provide useful information on the long-term effects of exogenous changes *ceteris paribus* and, at least, on the direction of the change resulting from a set of policy interventions. The direction of overall change may not be trivial when setting up many simultaneous policy interventions or when analysing a set of exogenous price changes. In some other cases, however, when analysing the effects of gradual policy shifts in a rapidly changing economic and policy environment and structural adjustment, a dynamic perspective and evaluation of different possible future paths may be more illuminating than static equilibrium exercises which assume instantaneous and full adjustment to all changes simultaneously. In other words, the assumptions of the underlying theory should not rule out the effects to be analysed.

Second, any set of assumptions and theories, however realistic, cannot be used in the same model. For example, one cannot use positive price elasticities of demand, even if they were consistent with data, in maximising producer and consumer surplus while assuming a unique unbounded solution. A model to be used in empirical economic analysis must be a theoretically consistent construction. In other words, different parts of the model should be based on theories and assumptions which are not contradictory or mutually exclusive. In addition to theoretical consistency, however, the model outcome should explain the empirical observations or stylised facts about the economy. If the model outcome is too abstract from the reality, it is difficult to link the model results with reality and give any policy implications. Hence, one has to decide between theoretical consistency and the ability to explain the particular forms of real world economic data. This decision is obvious in the field of econometric modelling, where the best possible specification and fit (i.e. the statistical properties of the parameter estimates), is often neglected in order to attain better theoretical consistency (see, for example, Jensen 1996, p. 65).

The trade-off between realism and consistency means sometimes a trade-off between neo-classical equilibrium economics and some alternative theories. The former theorising emphasises apriorism, i.e. a consistent set of assumptions concerning the rational economic behaviour, while the latter emphasises descriptive realism.

In this study, the starting point for model building is the neo-classical equilibrium theory, which is a natural and traditional choice in modelling agriculture since there are typically many farmers and quite homogenous products. It can be reasonably assumed that individual farmers maximise (or at least try to maximise) profits but are unable to influence market prices. A model based on these assumptions and representative farms, however, yields somewhat unrealistic results since the agricultural sector may not always be in the equilibrium. It may be difficult to replicate the actual data using the model if the economic agents have some incentives for changing their production variables. Furthermore, static equilibrium or moving equilibrium conceptions may not be sufficient for the analysis for adjustment processes of agriculture. In short, the assumption of static or moving equilibrium may be unrealistic. In such a case models describing adjustment processes in dis-equilibrium may also serve as more appropriate tools for policy analysis than equilibrium-based models. For this reason, some alternative paradigms of economic behaviour have been adopted from alternative theories of economics which are more flexible when modelling explicit dynamics, off-equilibrium transitions, technological change, uncertainty and limited perception. The resulting overall model is a consistent and appropriate mixture of the relevant assumptions and modelling techniques, tailored specifically for the analysis of Finnish agriculture.

5.2. The concept of economic surplus

First, let us discuss the basic neo-classical concepts used in optimisation-based agricultural sector models. Such models typically maximise the sum of consumer and producer surplus. Consumer surplus (CS) is, conceptually, the area between inverse demand function and price line, and describes the difference between the consumers' willingness to pay and the actual price of the product. Producer surplus (PS), which is the area between inverse supply curve and the price line, is linked to the profit of producers. The producer surplus can be considered an economic "rent" on the fixed production factors (which do not vary with output in the short term) not taken into account as production cost when calculating the producer surplus.

5.2.1. Consumer surplus

Consumer surplus constitutes the integral of the difference between the consumers' willingness to pay and the market clearing price, over the consumption set. Consumers' willingness to pay and thus consumer surplus is not directly observable.

Many assumptions have to be made, however, to ensure the validity of CS as a measure of consumers' utility. Assume that a consumer gets a certain utility from consuming any good. Consumer surplus can, in theory, be derived from consumer's utility function. Assume a rational consumer who is maximising his or her utility, according to some preferences, given a constant income. Thus the consumer has to choose the quantities of each good purchased in such a way that the total utility deriving from the consumption of each good is maximised subject to the income constraints. The consumer demand is assumed non-satiated, i.e. a greater amount of any good is better than less. However, the marginal utility of each additional unit consumed is decreasing when the consumption level of that particular product is increasing. In other words, the utility function of a consumer is monotonously increasing and concave.

A consumer is assumed to be able to rank any goods on the basis of his or her preferences. A consumer is also willing to substitute any good for some quantity of another good. The equi-utility curves (or equi-utility surfaces, in the case of more than two goods) are assumed to be convex, i.e. the marginal utility of any good is decreasing when increasing the consumption of that particular good. This means that the marginal rate of substitution is decreasing in quantity consumed. The more a certain good is consumed, the less a consumer is willing to increase the consumption of this particular good while decreasing the consumption of some other good. If this was not the case, a consumer would consume only one good, the one whose utility is the greatest at given income. While assuming convex equi-utility curves the utility maximising consumption level of the two goods is exactly at the point where the marginal rate of substitution (MRS) equals the price relation of the two goods (Silberberg 1990, p. 303-308; Varian 1992, p. 94-96).

$$MRS = \frac{dx_2}{dx_1} = -\frac{p_1}{p_2} \tag{5.1}$$

To ensure a unique solution for the utility maximisation problem, it is assumed that utility function is differentiable, strictly increasing and strictly quasi-concave. These assumptions, are, in normal cases, in accordance with the actual observed behaviour of consumers (Silberberg 1990, p. 176-180, 307-308). The maximisation of the utility function (with the described properties) yields the demand functions as a result of the first and second order conditions.

Consumers are assumed to be able to rank the different goods, or different bundles of goods. Consumers may not be able to evaluate the value of the goods in some absolute sense. Thus the exact functional form of the utility function can be chosen freely, given concavity of the utility function and convexity of the equi-utility curves.

The demand functions derived in the way described above can be used in measuring consumers' utility using the concept of consumer surplus. When considering more than one price change and the resulting changes in consumer surplus simultaneously, the area between the inverse demand function and the price line is not generally valid when measuring consumer surplus. The change in consumer surplus depends on the sequence of successive price changes. It can be shown, however, that the area between the inverse demand function and the price line is a valid measure of consumer surplus in the case of homothetic or quasi-linear utility functions (Johansson 1991, p. 42-47; Silberberg 1990, p. 597).

In the case of quasi-linear utility function the change in the income available for consumption would change the consumption of only one product while the consumption of all other goods would remain unchanged. In the case of homothetic utility functions all change in income would result in an equal relative change in the demand of all products. (Johansson 1991, p. 44).

Both homothetic and quasilinear utility functions can be considered unrealistic descriptions of the actual consumer behaviour. However, homothetic utility is assumed in this study since the marginal rate of substitution is independent of the income level, or the total utility level of consumers. While assuming homothetic preferences one can thus assume constant marginal rates of substitution between the goods.

5.2.2. Producer surplus

Producers are assumed to maximise profits. Producer surplus, which constitutes the integral of the difference between the market clearing price and marginal cost of production (the inverse supply curve), is directly observable since it is proportional to producers' income. The producer surplus, however, does not take fixed costs into account. Hence, the producer surplus (PS) is a valid concept only in the short term. Since fixed costs do not vary with the output, the sum of all marginal costs must equal to the total variable costs. If all production factors were variable, anyone could purchase production inputs needed for production and produce at marginal costs. Consequently, when calculating producer surplus, some fraction of the total costs have to be fixed costs. There is usually, at least in agriculture, some fixed production factors needed to set up the production system whose costs can be allocated on several short-term time periods. There may also be economies of scale involved in the production systems which make small-scale production more costly than the already existing large-scale production. However, if the market price is any higher than the short-term marginal cost, it must be the case that for some individuals it is more costly to set up the complete production systems than buying the products at the market price. While calculating the producer surplus the fixed production factors must be assumed sunk costs which do not affect producers' behaviour in the short term (Pindyck and Rubinfeld 1995, p. 255-256; Hanley and Spash 1993, p. 41).

Producer surplus accrues to the owners of the production systems. An owner may hire the complete production system to an entrepreneur who pays some rent to the owner. It is not rational, however, for an entrepreneur to pay any higher rent than the producer surplus at any time period (Hanley and Spash 1993, p. 41). In the long term, fixed production factors should be covered by the cumulated sum of rents. Thus the cumulated sum of producer surplus must be large enough to cover the fixed costs. In competitive markets, however, the cumulated sum of producer surplus cannot be any higher than the value of the fixed production factors. In the long term, all production factors are variable and there is no producer surplus in competitive markets. Hence, producers gain zero profits in perfectly competitive markets in the long term (Pindyck and Rubinfeld 1995, p. 256-263).

5.3. Equilibrium and time

5.3.1. Optimisation and equilibrium in neo-classical theory

Market behaviour can, in principle, be described by an optimisation model maximising producer and consumer surplus. This maximisation is constrained by market clearing conditions as well as constraints on production technology and capacity. Some other constraints can also be taken into account. A unique solution of this optimisation, usually ensured by imposing appropriate functional forms, represents a competitive equilibrium. In agriculture, in particular, agricultural supports, production quotas and other policy measures influence this market outcome and thus also economic surpluses of producers and consumers.

The time domain of an equilibrium model maximising the sum of consumer and producer surplus determines, which costs are taken into account in the model. In a short-term model fixed costs are sunk and do not affect the behaviour of producers. Producer surplus may be positive in short-term analysis, but is strictly zero in long-term analysis of perfectly competitive markets when all costs are considered variable costs. Prices are thus simply production costs divided by the production quantity. It is common in practical equilibrium analysis to consider short term and long term separately. The short-term results are obtained by restricting the fixed production factors and assuming sunk costs. In a long-term analysis all production factors are allowed to adjust to changed economic conditions. However, there is no formal link between the short and long runs in static equilibrium analysis, i.e. how the shift from the short run to the long run takes place, and how investments are made. The long-run results are thus assumed independent of the actual process of adjusting the fixed production factors.

The basic hypothesis in the equilibrium analysis is that economic agents maximise their profit or utility but cannot influence market price through their individual actions. This maximisation results in a market equilibrium and the equality of market price and marginal cost of production (Silberberg 1990, p. 492-493). When applied in economic and policy analysis of agricultural sector, the reactions of supply and demand are considered to reflect the joint effects of different policy measures, given profit and utility maximisation, i.e. simulation of efficient markets (Hazell and Norton 1986, p. 160-162, 167-168).

In partial equilibrium framework the general notions of efficiency are not applicable, however. In partial equilibrium models the prices of commodities may be endogenous, while the incomes of consumers are exogenous. Demand functions can be made dependent on exogenous income of consumers, and thus one may analyse the income effects on the demand and supply of agricultural supply. This, however, may be deceptive, since in a partial equilibrium framework there is no way to model the fraction of income spent on, say, agricultural products, because other products in the economy are not included. Thus, one should not make general efficiency and welfare implications using a partial equilibrium model.

5.3.2. On rationality and bounded rationality of economic behaviour

Neo-classical economic theory and equilibrium analysis is based on the assumption that firms maximise profit and consumers maximise their utility. Maximisation hypothesis is rational, since no reasonable person, firm or institution, when given two alternatives with known outcomes, would choose the one with the inferior outcome. In consumer theory, for example, it is assumed that consumers are always able to make rational choices between the alternatives, according to their preferences. This is hard to be proved or refuted, however, since almost all economic behaviour can be explained by some specific preferences or a highly constrained choice set (Fusfield 1996, p. 308; de Vriend 1996, p. 268).

The explicit optimisation, often with perfect knowledge, with no calculation or information costs imposed to economic agents, and sometimes with no uncertainty, has received much criticism of being too abstract from reality and implying too simplistic and too mechanical a view of economic behaviour. Consequently, “bounded rationality” arguments and “routines” of economic agents have inspired many economists and produced new directions of economic research. The concept of “bounded rationality”, “limited cognition” or “limited perception”, also appears in evolutionary economics domain. Nelson and Winter (1982, p. 99-136) discuss routines and rules of thumb extensively in their attempt to contribute to the formulation of evolutionary economic theory. In fact, limited perception of available choices is one building block of evolutionary economics. Limited perception does not mean that economic agents would be irrational, but that they do the best they can and know (Dosi and Nelson 1994, p. 162).

According to Dosi and Nelson (1994, p. 159) the behavioural foundations of evolutionary theories of economics rest on learning processes involving imperfect adaptation and mistake-ridden discoveries. Successful discoveries may lead to innovations which create new variety and thus a heterogeneous population of economic agents. It is exactly the creation of new variety, novelty, as described by Witt (1993, p. 91-92), and new innovations which distinguishes evolutionary economics from adaptive economic theory of Day (1978). Adaptive economics paradigm as presented by Day (1978) (presented in Chapter 3) contains only the first two of the three criteria of evolutionary models. Those two criteria are (1) dynamics and (2) irreversibility. The third criterion is (3) variety creation, i.e. novelty, either in the form of new products or production techniques, are created by economic agents through innovation processes and learning. Criterion (2) rules out all dynamical trajectories with stationary states or equilibrium movements. However, RP models may, or may not, converge into a particular equilibrium. In evolutionary models convergence to a steady state equilibrium is very unlikely and almost impossible because of the creation of novelty, limited perception and the lack of explicit optimisation, which is necessary for an equilibrium (Dosi and Nelson 1994, p. 157-158). In equilibrium, every economic agent makes the optimal choice, given the optimal choices of all other agents.

According to de Vriend (1996), only preferences and perceived opportunities have eventually some significance in economics. Defining rationality in economics in the way presented above one has emptied the notion of rationality of all (normative) substance (de Vriend 1996, p. 268-269, 281). Thus the classical framework of economic behaviour is quite large and works consistently even in ”evolutive” models with uncertainty, limited perception of alternatives or limited intellectual capacity. When assuming “bounded rationality”, or cautious sub-optimisation, for example, there is an explicit or implicit optimisation model to which the behaviour of an economic agent is referred to. Comparing alternatives and making choices is actually implicit optimisation, often with uncertainty and limited perception of alternatives. However, the ultimate goal of rational economic behaviour is to make optimal choices (if different courses of action and their costs are correctly specified), and this goal seems to be common to neo-classical and evolutionary economics. The explicit optimisation employed in neo-classical economic models can be seen as an abstraction and assumption that economic agents can be modelled “as if” they optimise. Cautious sub-optimising presented by Day (1978a) is a way of modelling economic behaviour “as if they sub-optimise”, which assumes uncertainty and limited perception. According to Day (1975, p. 27) it is often necessary and convenient to use explicit optimising models of behaviour, because of the extreme complexity of human economic activity. Either way, purely optimal or sub-optimal behaviour is an abstraction of reality. The plausibility and realism of the assumptions concerning the economic behaviour of individuals, however, should fit the problem at hand and the model results should be evaluated on the basis of the initial assumptions.

One can find purely economic reasons for seemingly sub-optimal behaviour (for example, for the overproduction in agriculture discussed in Chapter 5.4) because it may be costly to change the set of perceived opportunities. Information is not free of charge, but often requires search costs.

Pingle and Day (1996) present a study of different economising modes of economic agents. Sterman (1996) argues that existing studies in psychology would illuminate the changes in perceptions of individuals and some sub-optimal behaviour, like anchoring the decisions in the neighbourhood of suggested prescribed clearly sub-optimal choices, as suggested by Day and Pingle (1996). Some economists, at least some economists of a "behavioural school" (represented by Simon 1959, 1986, for example), seem to have an inclination of explaining economic behaviour in psychological terms. Pioneers of evolutionary economics, like Nelson and Winter (1982, p. 36) were "in sympathy with behavioralist position" and adopted behavioural rules similar to ones explored in the behavioural school of economics as a building block of their early evolutionary models. However, psychological considerations do not, at least explicitly, appear in Nelson and Winter (1982), and in other main texts of evolutionary theorising explicit psychological arguments are also hard to find.

Apparently, the motivation for psychological considerations in the behavioural school of economics was that by making assumptions of specific individual preferences one would be able to derive certain aggregate characteristics of aggregate behaviour. As shown in a survey made by Kirman (1992), in aggregate, the assumptions of individual preferences have, in general, no implications. It is theoretically impossible to get the necessary characteristics of aggregate demand functions, for example, necessary to prove the stability of the tatonnement process by imposing more and more restrictions upon the characteristics of individual demand functions. In other words, the aggregate economic behaviour cannot, in general, be derived from a large number of different kinds of individual economic behaviour (Kirman 1992). Approaches that rely heavily on specific psychological arguments of individual preferences may not be viable in deriving aggregate level implications. Furthermore, perceptions may be subject to frequent changes through market feedback, for example, or through observations of the behaviour of other individuals. Thus, approaches that rely less on specific assumptions concerning individual preferences may be more promising in terms of economic analysis.

To avoid the threat of economics slipping into the psychology of perception, de Vriend (1996, p. 280-281) proposes a framework in modelling of economic agent's actions as a function of perceived opportunities where the relations between actions and previous actions are flexible. Through learning the perception of alternatives evolves over time. The set of perceived opportunities may depend on the outcomes of earlier actions of many economic agents, i.e. market feedback, which, in turn, may depend on earlier perceptions of opportunities. This idea is close to Day's idea of cautious sub-optimisation with feedback. Such an interaction between perceptions, actions and market feedback results in an essentially path dependent process of economic development, where the final state of the economy depends, not only on the initial position and the initial assumptions, but on the changes between the initial and final time points. It may not be possible to predict the final outcome of this process only on the basis of the initial position.

The concept of cautious sub-optimising is, to some extent, a combination of neo-classical economics and behavioralist and evolutionary theories of economics, which are more general by nature and include many features not included in RP models. Recursive programming models incorporate rationality in the form of explicit optimising but in a way that focuses on the central problem of systems dynamics and behavioural theories attempting to explain how economising takes place or how economies really work. (Day and Cigno 1978, p. 8). Some evolutionary models, on the other hand, may model economic behaviour explicitly by means of switches and rules and various kinds of learning mechanisms. Evolutionary models may also include R and D work, which may create, given some probabilities of success, new innovations and variety, whereas recursive programming models described by Day and Cigno (1978) have a constant choice set of technological alternatives. Evolutionary economics and evolutionary models try to describe the actual process of innovation both as a cause and effect of economic development.

Thus the scope of RP models which attempt to explain the choice of the existing technologies is quite narrow compared to evolutionary economic models. In fact, concerning technical change, the adaptive economics paradigm prevalent in RP models stays closer to the neo-classical paradigm than to the evolutionary theory. One can also find neo-classical models which choose between alternative, existing technologies. Like evolutionary models, the recursive programming models, however, assume technical change as a dis-equilibrium process rather than as a static equilibrium or a continuum of successive equilibria which are characteristic to neo-classical models.

5.3.3. Dis-equilibrium dynamics and evolutionary economics

The dis-equilibrium dynamics and the principle of cautious sub-optimisation adopted in this study are not any *ad hoc* ideas and methods of economic analysis, but are based on a rather long process of economic reasoning and theorising. The ideas concerning "adaptive economic theory" presented by Day (1978a), for example, are by no means new. According to Day and Cigno (1978, p. 14-15), the idea of sub-optimisation with feedback was used explicitly or implicitly by such classical economists as Cournot (in the context of duopoly theory), Walras (in tatonnement theory), Marshall (in his quasi-rent theory of investment) and Kaldor and Leontief (in the cobweb theory of markets and in a model of economic growth). Some theorists of evolutionary economists in the 1990s refer to Marshall and to his specific statements, as "the Mecca of the economist lies in economic biology", which indicates that the economist Alfred

Marshall found biological metaphors of economics, i.e. dynamics, variety creation (innovations) and selection, appealing (Nelson 1995).

According to Nelson (1995, p. 49), writings in economic history are full of biological metaphors. When economists are describing or explaining particular empirical subject matter in a context that does not require explicit theory, they, like Marshall, do not use equilibrium language, but often use biological metaphors. This, according to Nelson, is an indication that many economists have seen biological conceptions more illuminating than mechanical analogies. For example, Marshall emphasises the importance of dynamics, change and movement, and uses some biological metaphors, but finds it difficult to incorporate time in the equilibrium analysis (Hart 1996). According to Nelson (1995, p. 50), economists who use the language of development and evolution apparently do not believe that concepts like optimisation and equilibrium can adequately explain economic phenomena. However, there have been relatively few efforts, compared to the number of modelling efforts exercised in mainstream economics, to build an evolutionary economic theory or complex economic models behaving like biological systems. One reason for this is the belief that to do so would make the models intractable, or too complex and difficult to understand (Nelson 1995, p. 49).

The origins of evolutionary theorising in economics date back to the 19th century, if not to even earlier times. Critical views on static equilibrium economics and some alternative views on economic development can be seen in the writings of Karl Marx in the late 19th century and of Joseph A. Schumpeter in the early 20th century. Schumpeter, in particular, presented ideas which have greatly inspired evolutionary economists (see, for example, Andersen 1994, p. 1-21; Hagedoorn 1989, p. 4-5; Nelson 1995, p. 68; Nelson and Winter 1982, preface p. ix) and which are now one of the building blocks of evolutionary economic theory. According to Schumpeter (citation from Hagedoorn 1989, p. 23), tendencies to economic equilibrium are not the primary force of economic development, but "*it is the spontaneous and discontinuous change in the channels of flow, disturbance of equilibrium, which forever alters and displaces the equilibrium state previously existing*". Schumpeter, as well as later evolutionary economists, was not happy with neo-classical theory where economic growth is viewed as a moving equilibrium of a market economy, in which technical change is continuously increasing the productivity of inputs, and the capital stock growing relative to labour inputs. Rather, in spite of assuming continuing equilibrium with relatively small incremental effects of innovations, innovation and dis-equilibrium should be given more emphasis in explaining economic change (Nelson 1995, p. 67-68). According to Hagedoorn (1989, p. 23), the introduction of innovation as a dis-equilibrium force is the primary cause of cyclical movement of a two-phase cycle of prosperity and recession and a new equilibrium in Schumpeter's model. This kind of reasoning, which believes that equilibrium alone is not a sufficient tool of analysis of technical and economic change, seems to be typical for many evolutionary economists (Nelson 1995, p. 51). Still, almost all evolutionary theories of economic growth, in particular, draw inspiration from Schumpeter (Dosi and Nelson 1994, p. 161; Nelson 1995, p. 68).

In addition to Schumpeter and the Austrian school, there are some other economists and economic schools of thought in the 20th century which have criticised neo-classical static equilibrium analysis and developed dynamic (dis-equilibrium) methods or dynamic economic theory. One such a school is the Stockholm School in the 1930s and 1940s. Some economists of the Stockholm School criticised comparative statics, i.e. equilibrium theory as a timeless theory (instantaneous adjustment), not explaining the traverse between two equilibrium situations (Hansson 1982, p. 93, 96). Consequently, it was concluded that "*a dynamic analysis must precede the static analysis and not vice versa*" (Hansson 1982, p. 97, 198). It was considered that statics, or equilibrium theory, play a role in determining the direction of development. However, during the traverse to a new equilibrium new disturbances may occur, and these disturbances are not necessarily exogenous but they may have an endogenous character. Hence, the traverse affects the process of attaining a particular equilibrium of that implied of static equilibrium theory. Thus the velocities of economic adjustment must be taken into account in the analysis of an adaptation process (Hansson 1982, p. 101, 223). It was seen that "*the dis-equilibrium method in nearly all cases gives the necessary starting point for dynamic analysis, and that this dis-equilibrium approach usually gives a sufficiently good account of potential tendencies for the purpose of making decisions about economic policy*" (Hansson 1982, p. 234-235).

The dynamic method of the Stockholm School was, after all, considered a theoretical tool which could be used for analytical purposes rather than something which was directly applicable to empirical analysis. Most of the empirical work done by the Swedes during the 1940s belongs to category of "single period analysis". This conclusion made by Hansson (1982, p. 235) is in line with Nelson's general conclusion (1995, p. 49), which states that despite the intuitive appeal, biological and off-equilibrium conceptions did not enter explicitly economic theory and modelling efforts except recently, and this is an indication of difficulties in developing a formal economic theory based on biological conceptions.

The complexity conceptions, however, do not pose the same analytic obstacles as was the case, say, twenty years ago. This is due to the increased computing power of computers as well as the availability of programming languages and softwares that facilitate the analysis and simulation of complex dynamical systems. The recent workings in complex dynamic and economic systems (see, for example, Nijkamp and Reggiani 1998; Day and Chen 1993; Day 1994) cover various fields of economics, like economic growth and fluctuation, interplay of technical and economic change, industrial organisation, economics of innovation, regional economics, stock market dynamics, and network economics. The empirical research in developing evolutionary models, in turn, has contributed to a rising body of evolutionary theorising in economics reviewed by Nelson (1995) and Andersen (1994). The explicit theory and tools are likely to result in an increasing volume of experimental models. In terms of computational burden and theoretical tractability, it is becoming less and less compelling to restrict modelling efforts to equilibrium-based neo-classical approaches.

5.3.4. Efficiency considerations

According to the first welfare theorem, competitive equilibrium under perfect competition corresponds to Pareto optimal consumption and production allocation. An efficient allocation is a result of trades of many individual economic agents who trade until nobody's utility or profit cannot be increased without lowering the utility of someone else. The second welfare theorem states that each Pareto optimal outcome corresponds to a competitive Walrasian equilibrium if preferences are convex, continuous and monotonic. (Silberberg 1990, p. 587-589; Varian 1992, p. 326). The allocation maximising the welfare of the general economy under perfect competition is thus Pareto efficient.

The market equilibrium outcome of perfect competition represents an efficient allocation of production and consumption. In general, under perfect competition there are an infinite number of possible Pareto efficient allocations. Considering two aggregate groups of economic agents, namely producers and consumers, the efficient market outcome can be found on an equi-utility curve of producers and consumers. On such a curve the utilities of producers and consumers can be traded only in such a way that neither group can increase their utility without lowering the utility of the other group (Samuelson and Nordhaus 1984, p. 487; Baumol 1977, p. 503-506).

In a dis-equilibrium modelling framework all the results and conclusions concerning the efficiency are lost since in dis-equilibrium all economic agents have not fully adapted to the economic environment and to the actions of other agents. Given the inclination of many economists to emphasise efficiency issues in economic analysis, this might be considered a disadvantage or a price to be paid in order to provide dynamic dis-equilibrium analysis. Efficiency and welfare considerations are frequently used in motivating trade liberalisation schemes (for example, Törmä and Rutherford 1993, p. 57).

It is important to recognise, however, that also some inherently neo-classical models built on standard assumptions may fail to provide valid efficiency results. It has been shown in a static framework that competitive markets under risk are not generally Pareto efficient when producers are risk averse (Chavas

1994, p. 125). Concerning dynamic analysis of agricultural investment, Chavas (1994) shows that under both uncertainty and sunk cost and in the absence of risk markets (markets on which risks can be traded and shifted to another company) resource allocations are not Pareto optimal. Thus, the efficiency measures are valid only under rather restrictive assumptions. Such assumptions, like risk neutrality and absence of sunk costs, or perfect risk markets, are quite unrealistic when considering Finnish agriculture. Thus, despite the inclination to efficiency considerations of many agricultural economists (like G.L. Johnson 1982, p. 775), such considerations should be exercised very carefully in the case Finnish agriculture. It is important to recognise that the efficiency considerations in which information from consumers directly and immediately affects the production decisions of farmers do not fully apply to Finnish agriculture. Sunk costs and uncertainty result to non-Pareto optimal losses imposed on imperfectly informed investors as well as on consumers.

5.4. Investments and technical change

Investments to more efficient production techniques are a driving force of technical change in Finnish agriculture (Niemi et al. 1995, p. 12). Some part of the technical change is directly connected to economic conditions while some part of the technical change is not. For example, the evolution of the genetic production potential of dairy cows is somewhat independent of the specific production technology invested by farms, while a variety of production costs, like labour and capital costs, are greatly influenced by the farm level technology choices. The former part of technical change, imposed by achievements in animal and plant biology, is mainly carried out by agricultural and biological research institutions and, at least in short and in medium term, is largely independent of economic conditions of agriculture. Such research work, like introducing new plant varieties, requires a dedicated work of several years before the new innovations can be applied in the actual production.

While recognising fundamental changes in economic environment, however, the biological research may give more emphasis on some specific aspects and objectives of the research. Nevertheless, the basic biological and technical research is not directly steered by the economic decisions of farmers but by government actions which evaluate and steer the work of agri-biological research institutions. Organisational inertia as well as lags in evaluation process and in the governmental decision-making are likely to make the research institutions respond quite sluggishly to changed economic conditions. It is also difficult to assess the probabilities of success or the quality of the outcomes of biological and technical research work. Hence, in the analysis of aggregate behaviour of many individual price-taking farmers who cannot influence the directions of biological research, the increase in biological production potential is better to be modelled as exogenous. It depends on the economic conditions to what extent this potential is utilised.

Technical progress, however, requires more careful analysis. Investments in specific production techniques and the scale of investments are influenced by prevailing economic conditions as well as expectations of future economic conditions. In any economic or policy analysis it is thus problematic to assume some constant rate of technical progress which is used in several policy scenarios. It is preferable to model explicit investment decisions which describe the choice of technology as well as the scale of investments explicitly as a function of economic and policy variables. This, however, is a difficult task since it is difficult to show the empirical validity of the specific investment rules (at least in large samples) when compared to the actual investment behaviour of farmers.

Using normative investment rules one may derive misleading responses to changed economic conditions. According to Dixit and Pindyck (1994, p. 419-425), modelling aggregate investments is one of the less successful areas of empirical economics. For example, some recent investment models based on real options, which have been successful in micro level analyses, have not been successful in explaining the observed aggregate investments. Real option means that a proper cost of an investment is not only the direct investment costs but also includes the option value of waiting for additional information of uncertain future revenues. If a firm waits, it is able to eliminate its risk by choosing not to invest.

Pietola (1997) constructed a generalised model of investment of the Finnish hog sector. The dynamic optimisation model of Pietola, based on the real options approach, accounted for stochastic input and output prices as well as irreversibility and adjustment costs. The model had two quasi-fixed capital goods, real estate and machinery. Data consisted of price indices and farm accountancy data over the period 1976-1993. There were 275 farms in the sample used in the study. When estimating the model parameters using full information maximum likelihood (FIML), Pietola (1997, p. 63-67) obtained quite a flat likelihood function around the maximum in the parameter space and detected poor performance when explaining real estate investments. When assuming binary choice of investment (to invest or not to invest) 55% of the real estate investments could be explained by the model, i.e. only slightly better than predicting investments on a toss of a coin (Pietola 1997, p. 66). Model performance when predicting machinery investments, however, was better. The percentage of correct predictions was over 80%. However, positive machinery investments were over-predicted, i.e. there were somewhat less machinery investments in the sample than predicted by the model. Considering the real estate and machinery investments together, the product of the two probabilities gives close to 45% probability of predicting both types of investments correctly, while two tosses of coin would give, on average, a correct prediction at the probability of

25%. Nevertheless, the model does not predict well in the cases where both investments are positive or both investments are zero. This is unfortunate, since it is known a priori that farms investing in real estate must, in normal cases, invest in machinery, too.

According to Pietola, the low predicting power of the model may be caused by farm-specific individual effects could not to be accounted for (Pietola 1997, p. 67). It is also concluded by Pietola (1997, p. 83) that real estate, machinery and labour adjust sluggishly to the shocks in exogenous variables. Especially machinery is reported to adjust very slowly to the steady state level. Possible explanations for this, proposed by Pietola, are unobserved individual tastes (i.e. farmers prefer new machinery the old), or tax shields imposed on machinery purchases. On the basis of the estimation results it is also concluded that sluggish labour adjustment is a consequence of inflexible labour market, which means that farmers are not able to get additional labour when needed, and farmers have few opportunities to work outside agriculture.

The failure of explaining aggregate investment behaviour by structural investment rules assuming far-sighted optimisation behaviour may be due to the following reasons. First, the dynamic optimisation with forecasted prices and estimated properties of the stochastic price processes may exaggerate the rationality and far-sighted behaviour of economic agents. It is possible, as Day (1978b, p. 342) put it, that farmers incorporate explicit strategic considerations only when they have evidence that far-sighted behaviour and explicit dynamic optimisation pays off. In the case of considerable uncertainty of future prices and subsidies it is possible that cautious short-horizon tactical behaviour performs better in explaining aggregate investment behaviour than long term strategic behaviour.

Second, investments are influenced by significant farm-specific factors. Farms, even of the same size, are not identical in terms of opportunity costs (potential sources of income outside agriculture), production costs, management skills, age of a farmer, access to land, capital availability, or existing capital stock. Farmers may have different expectations of future economic conditions as well as different attitudes to risk, which imply different investment behaviour even in homogenous groups of farms in terms of farm size and location. Even if farmers would make far sighted strategic decisions using explicit stochastic dynamic optimisation the overall investment behaviour would probably not be well explained by the strategic decisions of one or more representative farms because of the heterogeneity of farms.

When considering both the uncertainty of future prices and support, and the diversity of farms, it becomes clear that using normative far-sighted investment models in explaining aggregate investment behaviour becomes problematic. Actually, in the case of large diversity in the parameters and decision criteria affecting farmers' investment behaviour, any attempt to model investments at the level of representative farms is problematic. At least one should be able to classify farms in many representative groups with distinct sets of several factors, like opportunity costs, farm size, age of the existing capital stock, as well as land and capital availability. Hence, one should process an extensive set of farm level data in order to identify common factors to be used in the classification. This requires a large representative sample of farms with a large data set on each farm. All the many factors influencing farm-level investments vary between the farms. Consequently, it may be difficult to decide on which basis to form coherent groups of representative farms, i.e. what criteria to use in the classification. When forming groups as homogenous as possible, the number of farm groups is likely to become large, and representative farms of each group has to be based on the data derived from relatively few farms.

Recent neo-classical investment models of aggregate investment behaviour are explicitly assuming dynamic stochastic optimisation behaviour of farmers (Dixit and Pindyck 1994). Aggregate behaviour is based on equilibrium assuming rational expectations, i.e. all the agents are able to forecast, at least approximately, the aggregate investments and prices in equilibrium, on which they base their investments decisions (Dixit and Pindyck 1994, p. 250). This, however, cannot be seen as a very realistic assumption in the case of Finnish agriculture. Because of the revolutionary change in economic conditions in 1995, future prices and subsidies were largely unknown before and also after the EU integration. Stochastic price processes changed radically in 1995. Since then the future supports have been known for only 1-3 years ahead. Details of Agenda 2000 agreement, for example, decided by the EU ministers of agriculture in March 1999 were not known until the very last minutes before the deadline. Another major revision of agricultural policy is to come in 2006, at the latest. Given the farm-level diversity, uncertainty of future prices and support, as well as the poor performance of the real options based approach in explaining aggregate level investments, as reported by Pietola (1997), there is a good reason for testing alternative approaches in modelling aggregate investments.

The approach to modelling technical change and investments should, however, be compatible with the assumption of dynamic dis-equilibrium motivated in Chapter 5.3.3. In the domain of evolutionary economics the technical change and investments are essentially dynamic processes of dis-equilibrium which are unlikely to converge to a steady state equilibrium. The actual reasons for investments to more efficient or more productive techniques are often motivated by dis-equilibrium, i.e. incomplete adjustment to prevailing economic conditions.

This view of investments and technical change does not exclude investments in an equilibrium, however. If some exogenous achievements in science and technology make it possible to get higher profits, investments are likely to occur in equilibrium. In that case the technical change is an exogenous shock for an economy already in equilibrium. In a neo-classical setting one thus analyses how the equilibrium changes in response to exogenous changes in technology parameters. This view of consecutive equilibrium movements due to exogenous shocks, however, assumes rapid and simultaneous adjustment of the economic agents and does not analyse the paths to the new equilibrium position. Such a view is quite optimistic concerning the efficiency of markets and individual's ability to make sudden optimal adjustments. The adjustments may take time before any equilibrium is attained, and in the meanwhile other exogenous shocks may occur. Because of the diversity of economic agents, uncertainty, dynamics, dis-equilibrium can be seen as a usual state of affairs in agriculture. Thus it is reasonable to model explicit off-equilibrium investments and technical change, which includes both exogenous and endogenous components.

This kind of approach, which models agricultural production, investments and technical change as a dynamic dis-equilibrium process, has been rarely implemented as a large agricultural sector model. There may be fears that such a modelling exercise yields models that are too complex to understand, difficult to validate and costly to set up. As a result of theoretical and empirical simulation work in this area of economic modelling, however, the tool kit of modelling technological and economic dynamics is significantly richer than, say, 10-20 years ago. If such an approach can provide insights valuable for agricultural policy makers, not easily covered by traditional equilibrium approaches, further explorations of the approach are necessary.

In this study, exogenous technical change is used as a starting point and as a first approximation before more detailed and more structural modelling of investments and technical change. There are relatively few similar applications in the literature. All aspects of investments and technical change, as well as all the problems related to model validation and specification, cannot be included or solved in this study. The level of detail is increased gradually once the proper function of the previous modelling steps have been ensured.

5.4.1. Exogenous technical change

As already stated above, some part of biological and technical progress can be seen exogenous to farmers. In terms of increasing biological yield potential, one can model incrementally increasing production functions, for example, as a function of time. Thus the intensity of production, i.e. the levels of input use and yields, depends both on the exogenous growth in yield potential and on the prices of inputs and outputs.

Because of the difficulties in modelling sector-level investments, incomplete data, and the limited resources available to the modelling effort, it may be preferable to assume partly or completely exogenous technical change. Also in the case of great changes in economic environment and uncertainty, there is scope for modelling exogenous technical change. One can perform simple scenario analysis with different scenarios of technical change. Such analysis may reveal important insights and likely impacts of technical and economic change.

One may also perform agricultural policy analysis with different sets of policy measures while assuming a single set of technical change. Comparing between the different policy scenarios, however, may be problematic using a single and constant set of assumptions of technical change. This is because the economic and technical change are inter-related, at least in the long term. Economic conditions influence investments and technical change, and vice versa. In the case of great changes and uncertainty, some sensitivity analysis is needed in evaluating the direction and magnitude of the supply response. The impacts of a policy change can be roughly evaluated by using alternative scenarios of technical change.

Models with exogenous technical change should not be overlooked, however. Exogenous technical change is probably better than a model with no change at all. Each model should also be evaluated in comparison with the alternatives. Without any dynamic model with technical change, the information needs of policy-makers may be fulfilled by some other less analytical conjectures, like totally subjective assessments, or traditional normative models with obviously unrealistic behavioural assumptions. Such conjectures may provide completely mis-leading results. A systematic model-based analysis of the effects of technical change in a dynamic setting, even with exogenous technical change, may reveal many important insights and serve as a first approximation. It may be more desirable to use explicit sensitivity analysis with different technical parameters rather than to rely on the validity of subjective views. Highly structural investment models and parameter estimation using data from the forgone policy regime and economic environment may also produce misleading results. In the case of great economic change and uncertainty explicit sensitivity analysis may be more illuminating than the reliance on econometrically estimated parameters.

A very specific argument favouring even quite simple approaches of exogenous technical change in the case of Finnish agriculture is that the level of public investment aids largely determine the aggregate investments. In the provisions of investment aid programs there are detailed conditions concerning the farm size, for example, which a farm must satisfy to be eligible for the investment aid. The provisions concerning the farm size, in turn, imply quite a restricted set of choices of relevant production techniques. Thus the investments and technical change are, to a large extent, policy variables to be decided by policy makers. This obvious fact makes it quite interesting for policy-makers to perform policy analysis or simple scenario analysis on the impacts of exogenous technical change.

5.4.2. Endogenous technical change

One needs to find an appropriate way to model aggregate investments in a dynamic dis-equilibrium framework. A choice has to be made between the different approaches used in dynamic dis-equilibrium modeling, suitable for optimisation approach.

Day and Cigno (1978a) present some early attempts to include investments in recursive programming (RP) models. The investment decisions in RP models may be completely myopic, considering only the present time period, or they may be strategic in nature by calculating deterministic net present value based on explicit price forecasts (see Mueller and Day 1978, for example). Uncertainty and the concept of cautious sub-optimising inherent in RP models is reflected in more or less pessimistic forecasts and, simultaneously, more or less cautious modification of decision variables. When new information becomes available through market feedback, previous plans are revised using updated price forecasting rules.

Strategic behaviour based on forecasting and dynamic optimisation, at least at the level of representative farms, however, is not plausible in the aggregate level analysis of Finnish agriculture. This is because of uncertainty of future prices and support as well as the diversity of farms. Farmers do not invest or make their production decisions in order to maximise the joint total profit of all farmers or a representative average farm, but in order to maximise the farm-level profit. Given the less successful experiences of Pietola (1997) and notions of Dixit and Pindyck (1994, p. 419-425) concerning the modelling of aggregate investments, the strategic far-sighted investment decisions based on (stochastic) dynamic optimisation of a representative farm, or a few representative farms, is not an appropriate choice in modelling investments in this context.

Consider a large number of farms in a relatively uncertain economic environment with a large diversity of parameter values affecting investment decisions. In such a setting, typical for Finnish agriculture, the myopic aggregate investment behaviour has some intuitive appeal. Assume farmers are rational and make far-sighted investment decisions based on net present value maximisation. First, because of the diversity of farms, they have different action thresholds (Dixit and Pindyck 1994, p. 421). Even small changes in current prices or support may trigger some farmers to invest. Thus, because of the diversity and a large number of farms, the investment response to changed prices and support is quite smooth and continuous. There is always a small number of farms ready to invest and waiting for a positive price signal. Hence, one may assume that the rational optimisation-based decision making in a large heterogeneous population results in myopic investments decisions on the aggregate level, rather than in strategic investments decided by few representative farms. If farmers are somewhat myopic, i.e. short-sighted and consider only few years ahead in calculating future profits, the resulting aggregate response to economic changes is still quite continuous, because farmers are very heterogeneous with regard to their parameters, i.e. initial situation, and decision criteria, influencing the investments. Hence, the assumption of myopic and continuous aggregate investment response is not sensitive to the time horizon used in farmers' decision making because of diversity.

Thus the myopic but restricted short-term investments reflect the diversity of farms. The key issue, however, is how to restrict the level of aggregate investments from large and unrealistic annual fluctuations in a dynamic model. In the case of agriculture it must be assumed that only a fraction of farmers are able to invest at the same time because of the long duration of the investment cycle. The annual restrictions on investments could depend on the length of the investment cycle, i.e. on the annual depreciation rate and dis-investments. In the case of agriculture the possible dis-investments are limited because the investment goods applied in agriculture cannot be easily used in other sectors of the economy. Some dis-investments, in addition to normal depreciation, may occur, but the annual investments have to be quite restricted. In recursive programming context this means that one could simply impose bounds on the investment and dis-investment activities.

The short-run inflexibility of capital and investments to economic conditions means that some part of the fixed production costs, i.e. invested capital, is sunk and does not affect short-term production decisions. If all costs were variable, each of the outcomes of the annual optimisation models would characterise long-term equilibrium, not the short term reactions in dis-equilibrium. On aggregate level, however, some part of the production costs are always sunk costs. The flexibility constraints of investments in RP models would represent this factor fixity and affect the short-term supply response. In such a setting the farmers would almost always produce too little or too much relative to a long-term equilibrium. It remains to be evaluated if such behaviour is acceptable in economic analysis. According to Asset Fixity Theory (AFT), the answer is yes.

The AFT theory was presented in the 1950s, discussed later by Johnson and Pasour (1982), Johnson (1982), Bradford (1987), and was further motivated and established in an explicit dynamic framework by Hsu and Chang (1990) and Chavas (1994). According to Chavas, who presents a formal and general proof of the existence of "overproduction trap" suggested by AFT, the persistent overproduction results from sunk costs, i.e. the difference between the acquisition price and the salvage value of a capital asset. When the marginal value of production equipment, in terms of explicit expected profit maximisation, is between the acquisition price and the salvage value, there is no incentive for producers either to expand or contract their operation. Thus, in the case of uncertainty and sunk costs, the assets once purchased are "trapped" into their current use. This results from purely neo-classical profit maximisation of net present value embedded with uncertainty and sunk costs.

This notion is compatible with the dynamic equilibrium in a competitive industry where firms make investment decisions based on stochastic dynamic optimisation and rational expectations. In such a setting, as presented by Dixit and Pindyck (1994, p. 262-263), market prices will always lie within prices which trigger entry and exit of firms. Assume each firm has rational expectations about the price process between these barrier prices. The exit or dis-investments of other firms generate a floor, or a lower reflecting barrier, on the price process, whereas the entry or investment behaviour of other firms generate a ceiling or an upper reflecting barrier of the price process. Firms invest or enter the industry only if the market price is high enough to cover direct investment costs and the option value of postponing the investment and waiting for additional information. The firms will dis-invest or exit the industry if the expected net present value of the existing capital assets is lower than the lump-sum costs of exit. Thus the uncertainty and sunk costs imply that prices may be above long-run average costs without inducing entry or investments, or prices may be below long-run average costs without inducing exit. In the sense of traditional approach the difference between long run average costs and market price should not exist: in perfectly competitive markets prices equal marginal costs and long-run average costs. Hence, the inclusion of uncertainty and sunk costs explains the "dis-equilibrium" to be consistent with perfect competition (Dixit and Pindyck 1994, p. 267).

Rational expectations hypothesis, however, is not necessary for a dynamic equilibrium in a competitive industry. Firms which make far-sighted net present value maximisation, but do not anticipate the price changes resulting from the actions of other firms, also make optimal investment decisions in terms of timing of the investment. Such "myopic" firms[2] act as if they were the last firms ever to enter the industry and the stochastic price process was solely driven by exogenous shocks. Competitive firms who make rational expectations assume a different price process with the upper and lower bounds. Even if the optimisation problems of the myopic and competitive firms are different because of the differences in price process, the prices that trigger the investment are the same for both firms. The real option value of investment is zero in competitive equilibrium, since perfect competition eliminates all profits. In the case of positive profits of investment many risk neutral firms will invest until the price stabilises to the level where profit is zero. Thus the competitive firms see this (because of rational expectations) and expect only, at maximum, the trigger prices for investments.

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[2] This is a special kind of myopia, as assumed by Leahy (1993): The firm is far-sighted in the sense that it calculates present values, but is short-sighted in the sense that it assumes the price process it uses for present value calculations (of profits) to be unchanged. Such a myopic firm has static expectations regarding industry output, but rational expectations regarding other shocks that influence market price.

Myopic firms, however, expect the price process to continue unchanged after the investment. This makes the investment more attractive for a myopic firm than for a competitive firm. The myopic firm, however, recognises the volatility of the price process and thus the risk involved in investment. Hence, the myopic firm believes that there is an option value of postponing the investment, and no other firm will enter when waiting. This option value, which does not exist in competitive industry, equals the excess profits of investment resulting from the unchanged price process (believed by the myopic firm). Thus the excess profits expected by the competitive firm and the option value of investment (lost when invested) exactly offset each other. Consequently, the investment decisions of a myopic firm and a firm which has rational expectations of the other firms are equal. This result is presented by Leahy (1993) and Dixit and Pindyck (1994), for example, and it also holds in the case of risk averse firms.

Some assumptions are necessary for the myopic behaviour to be optimal in competitive equilibrium (Leahy 1993, p. 1124-1125). First, the investments must be infinitely divisible. This is not always the case in agriculture because of technical and practical reasons. However, in aggregate level, the discrete individual investments are very small, and one may consider investments as if they were infinitely divisible. Second, the returns to scale must not be increasing. This condition is not satisfied in agriculture, since farm-level cost calculations clearly show increasing returns to scale. However, the cost reduction becomes relatively smaller when farm size is increased (Ala-Mantila 1998).

The conclusion to be drawn from the optimality of myopic behaviour is that modelling dynamic evolution of markets using a myopic profit maximising agent is consistent with competitive equilibrium. Even if individual agents do not make fully rational strategic decisions, the overall strategic decisions of the agents result in a competitive market outcome. Thus the myopic behaviour can be assumed in dynamic models of competitive equilibrium and no inconsistency occurs. In the case of sunk costs and uncertainty, prices may not cover long-run average costs, capital may be somewhat sluggish to changes in economic conditions and some part of production costs may be sunk, i.e. there may be an oversupply during long periods of time.

Myopic agents may, and are likely to make errors in their investments decisions. Because of uncertainty and unpredictable shocks in economy, even fully rational agents may make decisions which later appear less profitable than needed in order to cover the initial investment costs. An indication of such an error is when price does not cover the long-run average cost. After this kind of error in the investment decision, a farmer may still keep on producing if the expected future profits are higher than the opportunity costs, i.e. working outside the farm. Because of this, it should not be surprising if capital does adjust very sluggishly to steady state values, as reported by Pietola (1997), for example, and revenues do not always cover the long-term average costs. As already noted, making errors in economic decisions because of limited perception or limited intellectual, or limited forecasting capability, does not contradict rational economic behaviour, i.e. profit maximisation with respect to perceived alternatives and their consequences. As stated by Johnson (1982, p. 774), asset fixity theory or real options approach to modelling investment decisions do not suggest irrational behaviour.

Recursive programming models and purely neo-classical models describe essentially the same phenomena, sluggish production response to the changed conditions due to uncertainty and fixed costs. The recursive programming approach is used in this study, however, since the far-sighted behaviour and explicit dynamic optimisation is not a plausible assumption in the case of representative farms, and because of the fact that dynamic optimisation approach has explained aggregate investment behaviour quite poorly. It remains to be decided how to model sector level aggregate investments in an RP model.

5.4.3. Models of technology diffusion

Technology diffusion means the development of the spread of technologies in the population of economic agents. Alternative products or production techniques need to be specified in order to model technology diffusion. Alternative production activities with different linear input-output-combinations can be easily incorporated in agricultural sector models based on the optimisation approach (Hazell and Norton 1986, p. 149), allowing the model to endogenously choose the optimal technique. Irreversibility of investments as well as uncertainty and sunk costs, however, make it problematic to assume sudden shifts in technology. In RP models one may also set some flexibility constraints for the scale of individual production activities to prevent unrealistic sudden changes in the applied production technology. Nevertheless, the problem of this so-called activity analysis approach is that farmers are assumed to be perfectly informed on the production techniques and capable of selecting and adopting the most profitable technique. Given the diversity of Finnish farms in terms of production costs, this is an over-optimistic assumption. If only few representative farms are used as supplying agents in the model, the linear activity analysis approach, which always selects a single most profitable technique, fails to explain co-evolution of several competing techniques simultaneously. In reality, farms use different techniques since one technique does not fit equally all farms.

One alternative to the activity analysis approach is the concept of technology diffusion. Models of technology diffusion describe the progressive distributional change in the spread of different production techniques (Hagedoorn 1989, p. 120; Karshenas and Stoneman 1995, p. 263), i.e. the process how the most profitable techniques become wide-spread over time. The pattern of diffusion follows the description of the process of innovation and imitation with few originators and a growing number of imitators or followers. This pattern of diffusion is generally pictured as a sigmoid (S-curve).

In the early phase of the diffusion number of users (or, alternatively, the share of the output produced or the proportion of the firms' capital stock embodied in the new technique) of the new technique increases quite slowly. There may be some scientific and technical difficulties related to the adoption of the new technique which need to be solved by the first adopters. If the first adopters find the technique useful and relatively profitable compared to the other techniques, other firms get interested in the adoption, and the number of adopters increase. This, in turn, results in the spread of information and knowledge of the new technique, and the number of adopters will grow faster. Those firms which anticipate the greatest benefits from the new technique or are the most capable of adopting the new technique most probably make the first investments in the new technique.

In the later phase of the diffusion the rate of growth in the number of adopters decreases because not all potential adopters have the same incentives or costs of adoption. After most of the potential adopters have invested in the new technique, the potential adopters remaining face relatively severe constraints for adoption and thus the rate of growth in the number of adopters decreases. Some potential adopters need some time for adjustments before the adoption. The success of new techniques may also stimulate the improvement of the existing techniques, which may slow down the number of adoptions in the new technique (Hagedoorn 1989, p. 121). In any case, the number of adopters will grow slowly in the later phase but will gradually go up closer to the number of the potential adopters. The diffusion curve having an S-shaped form is more flattened the more frictions there are for the adoption.

These S-shaped curves often encountered in empirical analysis of technology diffusion can be generated by different models, including logistic function, a so-called Gompertz function, the modified exponential function, the cumulative (log-)normal distribution function, all of which are based on slightly different assumptions. A large number of theories and models attempt to explain diffusion more specifically. Some models are based on Bayesian learning, reduction of uncertainty, and epidemic processes (Hagedoorn 1989, p. 120-121).

One way to separate different approaches in technology diffusion is to make a distinction between static and dynamic models of diffusion. In static saturation models it is assumed that a specific innovation is progressively adopted by an unchanging and essentially homogenous population of potential users. In a more dynamic approach to diffusion both the population of potential users and the innovation itself change during the process of diffusion. There may also be many successive technological variations or many simultaneous technological alternatives. Thus the process of diffusion is not characterised by a single diffusion curve but by an envelope of successive curves or different situations regarding diffusion (Hagedoorn 1989, p. 122).

Another way of differentiating between various approaches in technology diffusion is to separate between equilibrium and dis-equilibrium models (Karshenas and Stoneman 1995, p. 273). Equilibrium models tend to assume perfect information on the existence and nature of new technologies. Relating to this, one may make a distinction between evolutionary and non-evolutionary approaches (Karshenas and Stoneman 1995, p. 289-290).

The evolutionary approach rejects models that assume full information and rationality and instead postulates limited information and bounded rationality. Evolutionary diffusion models avoid confrontation between one old and one new technology, instead of considering that at any time there are a variety of technologies available and diffusion is the outcome of a process of competitive selection. Evolutionary approach, in general, emphasises diversity of economic agents and dynamics. Instead of determining, at any point in time, some equilibrium level of a penetration level of a new technology, the evolutionary approach undermines any attempt to treat diffusion as a final stage in the process of technological change. According to the evolutionary approach, any trajectory of technological development is an interaction between technological opportunity (innovation) and a diffusion environment (markets) in which one shapes the other and vice versa. There are joint phenomena of "diffusion through learning" and "learning through diffusion". Since design configurations of new technology are typically built in this cumulative fashion through interaction and positive feedback with their environment, this means that diffusion is clearly a dynamic and path-dependent process in which the history influences the technological development.

It is the constant learning and interaction of economic agents with one another which makes evolutionary approach distinct from *ceteris paribus* equilibrium diffusion approaches (Metcalfe 1995, p. 482-483). In the evolutionary approach diffusion is not between static unchanged technologies in an environment of fixed homogenous population (which means no actual spill-overs of knowledge since homogenous firms would learn nothing from the other firms). It is the interaction of heterogeneous differential knowledge and not the addition of identical knowledge which matters. Hence, spill-overs reinforce the tendency of firms to innovate differently. According to Metcalfe (1995, p. 447), it is asymmetries and the way they are generated which derive the economic selection process, which in turn determines how the relative importance of different technologies changes over time.

The evolutionary technology diffusion approach is suitable for dynamic dis-equilibrium models since technology diffusion implicitly assumes off-equilibrium process of technical change. This means that some economic agents have not, for some reasons, yet selected the best available technique. Evolutionary diffusion models also inherently assume technological change as a dynamic process as well as account for the heterogeneity of economic agents. For example, farmers have different production techniques and parameters influencing the investments to new techniques. This is why all farmers do not shift to new techniques simultaneously and do not have identical perceptions of the advantages of the new techniques over the existing ones. Technology diffusion is a continuous process which does not necessarily result in homogenous firms in terms of production technology, since one technique may not be optimal to all firms. The diversity of technology and production costs of firms may be persistent by nature and does not necessarily result in a steady state outcome with relatively little or no change in technology. For example, if only a fraction of firms are able to adopt a new technique, or if a technique is optimal only for some firms, the diffusion process may lead to increased diversity. Incremental development of each individual technique may further expand the variety of production techniques.

The process of technical change is a dynamic process where the increase of investments and the spread of knowledge of the new techniques influence the investment decisions of those farmers who have not yet invested. This process may be strongly path-dependent, i.e. the outcome of the dynamic process depends not only on the initial conditions but also on what happens along the way. The evolutionary view of technical change cannot be interpreted as a change in technology in response to exogenous variations in data, but rather as a change which occurs endogenously, possibly without adjustments to any equilibrium (Metcalfe 1995, p. 448). There may be dynamic linkages of actions of economic agents during the process. Since all economic agents may not be able to respond to changed conditions simultaneously, an exogenous change results in a dynamic sequence of actions. The outcome of a sequence of actions may be different from the outcome of simultaneous adjustments assumed in static models.

In evolutionary models the overall outcome of a sequence of actions may be sensitive to initial conditions. Actually, sensitivity to initial conditions is another name for path dependence, as suggested by Day (1994, p. 30-31). In diffusion processes, in particular, some small perturbations in the early state of the diffusion process may have a considerable cumulative effect on the later evolution of the diffusion. Small changes in parameters may change the overall pattern of the diffusion process. Traditionally this kind of behaviour has been considered unacceptable model behaviour which should be ruled out by appropriate assumptions, like imposing a sufficient number of regularity and curvature properties. However, according to some historic examples mentioned in innovation literature, path dependency is a significant part of reality (Dosi and Nelson 1994, p. 166-169). Relaxing the assumption of simultaneous actions and perfectly informed adjustments of economic agents inevitably leads to dynamic models and possible path dependencies.

The technology diffusion process may, and often does, involve irreversibility and sunk costs of investments. Once a certain technique has been invested in, it cannot be re-sold at the initial price but at the lower price. As already proposed by the asset fixity theory, capital is then trapped into its current use within some range of product prices. This effect, due to uncertainty and sunk costs, may result in lock-in to certain technological choices together with some other characteristics typical for processes of adopting new technology. Such characteristics may be, for example (see Hall 1994, p. 272), the following:

1. Increasing returns to scale in knowledge, i.e. a firm may use the existing knowledge based on the previous experiences more efficiently;
2. The costs of acquiring new technological knowledge are high compared to reusing and further increasing the existing knowledge;
3. Existing complementarities, i.e. the existing production system, include a specific combination of skills, supplier relationships, market reputation, etc. Abandoning one part of the system and adopting new approaches may result in inconsistency with the existing system. Changing one part of the system may require changing some other parts, too.

Lock-in has the consequence of limiting the number of possible paths of technical progress. In the short term, lock-in may favour firms with particular sorts of knowledge over those which lack it. In the long run, however, those "advanced" firms may be threatened by some other firms whose technological knowledge is entirely different, and the profit potential of the alternative technological approach is much greater than the traditional one.

Lock-in results in striking path-dependent patterns of technology diffusion. Even random factors, especially in the early phase of the diffusion process, may essentially affect the later technological choices. Due to increasing returns to knowledge at a firm level, and due to the spread of knowledge among the firms, there are also increasing returns to adoption. Techniques with greater initial market penetrations have an advantage over the newer, even more profitable techniques. The reasons for this include (according to Hall 1994, p. 273):

1. If the most penetrated technology is embodied in production, scale economies result in price reductions, which inhibit adoptions of new innovations;
2. Improvements in the performance of the penetrated techniques generated by cumulative learning in using;
3. Spread of knowledge and network externalities generated by a large group of users;
4. A developed structure of complementary support, such as maintenance services and reliability

Due to these factors, even superior new techniques may never be able to challenge the penetration level of the widely penetrated inferior techniques (Hall 1994, p. 275; Dosi and Nelson 1994, p. 166-169).

Markets often choose relatively complex products or technological systems, not individual elements of technological knowledge, and penalise or reward whole organisations and not specific behaviours (Dosi and Nelson 1994, p. 156). Thus it requires considerable effort to bring a specific technical innovation to a superior competitive position on the markets. Considering agricultural production systems, for example, the overall performance and reliability is likely to dominate in importance over the performance of some particular subsystems. If machines break down during a peak load period, like a harvesting season, and service and maintenance is difficult to get, considerable economic losses may occur. In such a case farmers are likely to consider the reliability of the overall service of the supplying firm of the production system to be of more importance than some (possibly relatively small) benefits obtained due to superior performance of some individual parts of the system. It is likely that the existing techniques with a relatively large penetration levels are considered more reliable than the new techniques with few users with possibly inadequate services. Uncertainty, or inadequate information on the performance of the new technology also deters risk averse farmers from acquiring new technology.

Given profit maximisation, or at least profit-seeking behaviour, the profitability and the spread of knowledge of the new techniques influence the rate of technical change. Considering first a single technique, the difference in profitability of the technique compared to the alternative techniques as well as the existing penetration level influences the development of the penetration level. One can thus write

$$\frac{df_i}{dt} = A(E_i - E_a)f_i \tag{5.2}$$

where f_i is the penetration level ("market share") of i technique, df_i/dt is the change in technique i's penetration level over a short period of time, E_i is a profitability measure of i technique, E_a is the industry-wide average performance measure of production, and A is a fixed and positive adjustment parameter. If E_i is greater (smaller) than E_a then the penetration level of i technique is increasing (decreasing). The rate of change depends on the existing penetration level and the coefficient A. Equation 5.2 is called Fischer's equation and used originally in population biology in modelling interaction of competing species (Hall 1994, p. 276). The larger the dispersion of the performance of the techniques, the faster is the increase of industry-wide profit performance. This implies increasing rate of investments to best performing techniques in the early phase of the diffusion process, whereas the rate of change will become very small if the technique reaches the level of a dominant technology and the performance of the dominant technology is almost identical to the industry-wide average. Hence, on the basis of equation 5.2 one would expect an S-shaped outcome of the diffusion of the best performing techniques.

In such a scheme, investments in several techniques, those which are more profitable than the average of all techniques, may increase at the same time. Furthermore, if the techniques are themselves incrementally improving their performance due to learning, the dispersion of performance of the firms in the industry may decrease, increase, or reach a level of statistically stable distribution. The persistent performance dispersion means that the industry is in a constant state of dis-equilibrium, in the sense that most firms are at any moment trying to catch up with the best firms using more advanced technology (Hall 1995, p. 286). Such an outcome would be in accordance with the empirical fact that there seems to be considerable and persistent relative differences in the production costs as well as profitability of firms in the same industry. As discussed in Chapter 2, Finnish agriculture is one example of such industries.

Thus evolutionary technology diffusion models are able to account for persistent patterns of inter-firm heterogeneity and different production costs in the same industry. This is in contrast to linear activity analysis models which select the best technique. In RP models one may, however, give upper and lower bounds for the investments to individual techniques. In the early phase of the diffusion process the best performing techniques would attract investment at constant rate (even though the investments would increase in absolute terms). Nevertheless, while using constant values of the flexibility constraints there is no mechanism to decelerate the technical change when the number of adopters comes close to the potential adopters. Contrary to the empirically observed common S-shaped pattern the flexibility constraints would mean that the investments in the best performing technique would always increase at a constant rate. Thus the RP models embedded with alternative linear techniques and flexibility constraints on the use of the individual techniques are not able to adequately replicate processes of technical change. To conclude, it is desirable to use an evolutionary model of technology diffusion when modelling technical change in a dis-equilibrium model such as the model outlined in the next chapter.

6. The structure of the DREMFIA model

The presentation of the model is as follows. Some features of agriculture are given special emphasis (as presented in Chapter 6.1) in order to meet the objectives of this study (presented in Chapter 1). An overview of the model is provided in Chapter 6.2. The basic building block, the optimisation model simulating the agricultural market, is presented in Chapter 6.3. Some specific adjustment processes are described in Chapters 6.4-6.6. Chapters 6.5 and 6.6 present two alternative specifications of fixed production factors and investments. Thus there are two versions of the model, one using the assumption of exogenous change (Chapter 6.5), and the other using a specific model of endogenous technical change based on technology diffusion (Chapter 6.6). The former model can be used in various kinds of scenario analysis of technical change, while the latter is a more structured way of modelling investments and technical change. Both models can provide insight to agricultural policy analysis, but the questions to be answered are slightly different when using the different versions of the model. The investment aid system makes the agricultural investments largely controllable by the amounts of aid and some constraints imposed on the new investments. Hence, the model of exogenous technical change can be used when examining the dynamic effects of different scenarios of supports and technical change on agricultural production and income of farmers.

The exogenous technical change, however, does not describe the actual process of technical change due to investments triggered partly by investment aid. The technology diffusion model describes the endogenous investments of agriculture which are influenced by the profitability of each technique and the initial spread of each technique.

6.1. The emphasised features of agriculture to be modelled

Agriculture is characterised by internal dynamics and interdependencies between the different production lines. There are considerable differences between the time spans and lags in the production in the different production lines. Lags and delays in production are due to technical and biological constraints as well as to fixed production factors. A disequilibrium of a certain degree is typical for agriculture. The interdependence between crop production and livestock production is very strong. Different production lines compete for the same production resources. The available arable land area and other fixed production factors, as well as set-aside and production quotas influence all production lines. There is variation in the production structure between different regions. Both final and intermediate products may move between the regions. In addition, agriculture and food production are in open competition with other EU countries. Consumers, for their part, influence the production volumes through their choice. There are trends in the consumption of foodstuffs indicating changing preferences. There is also competition between imported and domestic products.

Economic adjustment to major changes in agricultural policy, like the EU integration of Finland, may take several years. During this time other changes that are partly independent of the policy may occur. Such changes may happen, for example, in the consumer habits, prices of inputs, feeding of animals, crop yield levels, average yields of livestock, use of other production inputs (e.g. labour and capital) as a result of the increase in the average farm size or other rationalisation of production. These changes may strongly affect agricultural production. Consequently, these factors should be taken into account in policy analyses. This fact has also been mentioned in some agricultural modelling reports or modelling applications which are based on static models (see, for example, Apland, Jonasson and Öhlmer 1994, p. 126-127). However, in agricultural sector modelling, there have been relatively few efforts to model the internal dynamics or productivity growth of agriculture or farm-level adjustment mechanisms explicitly. Some efforts in this direction can be found in Bauer and Hendrichsmeyer 1988, Day 1978 and in Day and Cigno 1978.

Internal dynamics of agriculture, fixed production factors, and some nonlinear relationships inherent in agriculture are emphasised in this study. This may lead to increased complexity of the model. In such a model the policy effects may be dependent on initial conditions and exogenous variables. Unlike in static equilibrium models as well as in some dynamic models, possible sensitivity to initial conditions are not ruled out a priori in this study. Rather, possible sensitivity to initial conditions, is seen as a consequence of the empirically observed complex relationships in agriculture. Recognising such complexities may provide more insight to policy-makers and agricultural economists than models which rule out such complexities.

The aim is that a dynamic model to be constructed can provide more insight to the dynamic effects of agricultural policy changes – which themselves take place in a time-specific manner – than static models relying on ceteris paribus assumptions when examining the outcome of simultaneous adjustment of all economic agents to all simultaneous policy changes.

In addition to policy analysis, this kind of modelling scheme allows to search for solutions to the problems of agriculture. For example, one can examine how large productivity growth is needed under different policy scenarios to retain the existing level of production. On this basis it is possible to consider different ways of improving the competitiveness of agriculture. On the other hand, one can use the model to estimate the dynamic effects of new production technology or changed food consumption on agricultural production.

The model presented here concerns the so-called basic agriculture (excluding e.g. organic production), i.e. all the most important production lines. The production, costs, consumption, foreign trade, and price formation as well as the support system of agriculture have been modelled in detail. No explicit connections to other sectors of the national economy are made. Agriculture is a small part of the Finnish economy and agriculture has little effect on the other sectors. Especially, the feedback link from national economy to agriculture is very weak. The lack of such connections is not of crucial importance in the policy analysis. However, direct links from the national economy and from the consumers may have a substantial effect on agriculture. These connections are described implicitly through consumption trends, price elasticity of the demand, the price of labour, and inflation.

6.2. The overall structure

The basic structure of the model is presented in Figure 6.1. The development of the agricultural sector is simulated from 1995 till 2010. The core of the model is an optimisation block which maximises producer and consumer surplus. It provides the annual supply and demand pattern using the outcome of the previ-

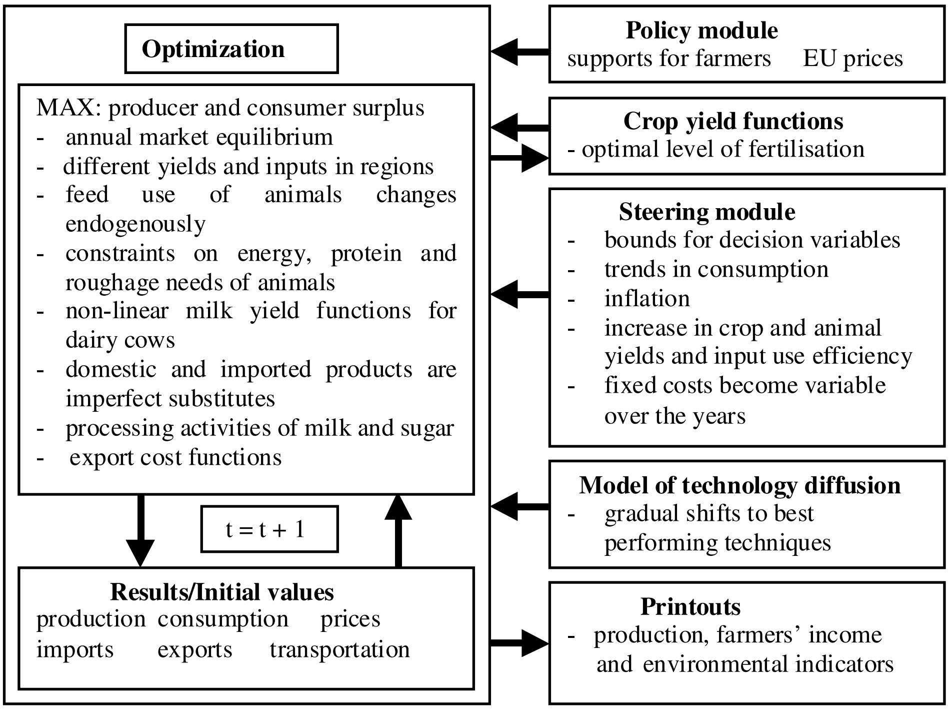

Figure 6.1. Basic structure of the DREMFIA model.

ous year as the initial value. Different kinds of production lags in the different lines of production are taken into account by imposing flexibility constraints on the production variables in relation to the preceding year. Hence, production may change only within certain bounds each year. These constraints imply that an individual optimum outcome does not correspond, in general, to the economic equilibrium, but only a short-term reaction towards an equilibrium at the prevailing prices and subsidies. Continuously changing policy, production technology and consumption trends, which are given exogenously from the steering module, results in continuous changes in agricultural markets. Even if the changes are restricted in the short-term, long-term changes may be considerable, if the price relations and policy causing the change prevail long enough.

The development paths obtained from the dynamic model are to some extent dependent on the given limits for change, i.e. the flexibility constraints. The absolute magnitude of the change may vary when using different limits for change, but the direction of the change remains the same. Someone may argue that the exogenously given bounds, the so-called flexibility constraints, always determine the model results. This may be the case in some simple dynamic models, but it is not the case in complex models like the present one. There are many interdependencies between the decision variables in the model and most often the bounds for the decision variables are not binding. However, the bounds for the decision variables are important for ensuring the realism of the model. At the farm level there are clear technical and biological restrictions in livestock production, for example, which prevent large short-term changes in production. One can also use time series of agricultural production to justify the bounds for the decision variables. The maximum allowable limits for change of the production are given exogenously in the steering module for the different production lines.

Flexibility constraints may, in principle, represent not only technical and biological restrictions, but also cautious sub-optimisation and risk averse behaviour of farmers. The risk averse behaviour of farmers means that farmers are reluctant to drastic short-term changes in production. Cautious sub-optimisation uses a one-period optimisation as the basis of choice without considering long-run trajectories based on explicit representation of the dynamic feedback of the markets (the concept of cautious sub-optimisation is also used by Day 1978, for example). It is assumed that joint groups of farmers, i.e. representative farms in the model, do not make forecasts of future prices and subsidies and do not make strategic long-term choices in the model. Rather, it is assumed in the model that representative farms do not make long term strategic decisions in a very uncertain economic environment but respond to exogenous changes with more or less caution. This is a reasonable assumption in the case of Finnish agriculture since future agricultural policy determined at the EU level and at the national level is highly unpredictable. Individual farmers, of course, may and do make long-term strategic decisions. At the aggregate level, however, it is hard to justify long term decision making and strategic behaviour in terms of representative farms. Farms are very heterogeneous in terms of future price and policy expectations and production costs which affect greatly the long-term strategic decisions. Such decisions are likely to be very different at different farms. Hence, it is problematic to assume some average farm which makes strategic decisions, or joints groups of farms which make joint strategic decisions. This issue is discussed and motivated in chapter 5.4.2.

In the optimisation model there are certain fixed inputs and outputs corresponding to many production activities (Leontief-technology). In the livestock sector, however, the use of feed is a decision variable, which means that animals may be fed using different feedstuff combinations. There are non-linear constraints relative to feed use. The required energy (measured in fodder units), protein and roughage needs of animals can be fulfilled in different ways. The use of each feedstuff, however, is allowed to change only 5-10% annually due to fixed production factors in feed production. This means that feeding of animals may change only gradually because of biological reasons and fixed production factors. Furthermore, changes in feeding affect the milk yield of dairy cows. A quadratic function is used to determine the increase in milk yield as more grain is used in feeding.

All foreign trade flows are assumed to and from the EU. It is assumed that Finland cannot influence the EU price level. For the part of imports, the domestic and the corresponding imported products are defined as imperfect substitutes (Armington assumption). The demand functions of the domestic and imported products influence each other through elasticity of substitution (Dixit 1988; Sheldon 1992, p. 116). The imperfect substitutability of domestic and imported products results in non-linearity in the model, which decreases drastic responses to changed economic conditions typical for linear optimisation models. Using this specification, consumers are assumed to prefer some domestic products, like domestic meat, and to be willing to pay 2-7 percent more for some domestic products. According to some surveys consumers in Finland have a strong preference to domestic products, and meat products, in particular, and are willing to pay more for the domestic products than for the imported ones. According to a survey made in November 2000 (Lihatalous 2/2001, p. 44). A majority of consumers accept only domestic meat.

Comparing the food consumption time series with the price time series one can easily find that price changes since 1995 have had relatively little effect on the food consumption (MTTL 2000, p. 43-44). The income of consumers has increased as well since 1995 but there seem to be little change in food consumption trends in 1990’s despite the decreased prices in 1995. Hence, it is reasonable to assume that the food consumption is more affected by consumer habits and lifestyle and less by food prices and income. For this reason the demand functions are used in order to model the substitution mechanism between the domestic and imported products, not the total consumption of each food item. This is also a reason why income, which would be an exogenous variable in the model, is not included in the demand function.

The total consumption of each food item were given exogenous trends on the basis of trend extrapolation. Most obvious trends can be found in the case of meat and dairy products. A decreasing trend at the rate of 1% a year is assumed for beef consumption, pig meat consumption is assumed to stay at the present level, and the consumption of poultry meat is assumed to grow 2% a year.

However, the total consumption may change 0.5-4% around the trend value in the model when maximising producer and consumer surplus. The upper and lower bounds for the total consumption were given on the basis of average annual changes in consumption in 1990's. For the part of meat, for example, the consumer surplus is maximised within a range of only 2% annually. Also prices may fluctuate depending on the given exogenous estimates of price elasticity of demand and substitution elasticity between imported and domestic products.

The known support for the different years and the anticipated support for the future years (the effects of which are being examined) are determined by means of a separate policy section. Together with the support policy, a scenario of the price level on the single market of the EU is also formulated.

The adjustment mechanisms of agriculture can be grouped into short-term and long-term mechanisms. In the base version of the model, only short-term mechanisms, such as changes in the use of some variable inputs, are endogenous. Fertilisation and yield levels are dependent on crop and fertiliser prices through crop yield functions. Feeding of animals may change within certain bounds provided that nutrition requirements are fulfilled. Specific production functions are used to model the dependence between the average milk yield of dairy cows and the amount of the grain based feedstuffs used in feeding. Thus, the yield of dairy cows responds to price changes of milk and feedstuffs.

Optimal farm-level fertilisation is calculated using the price level of the previous year (or intervention price in the case of a policy change) for crops and exogenous price of fertiliser as well as crop yield functions. Since the fertilisation decisions are based on the last year's prices or intervention prices the market mechanism does not affect yearly changes in the use of fertilisers or crop yield. Fertiliser prices, like the other input prices are exogenous in the model. Yield functions were obtained by adjusting empirically estimated yield functions to the average fertilisation and yield level in each region.

Long-term adjustment mechanisms include increasing productivity and production efficiency. Increasing productivity, such as increasing crop and animal yields because of improvements in the genetic potential of crops and animals, is partly independent of policy changes. The exogenous change in productivity is applied to the scalar parameters of the production functions only. Hence, prices and subsidies determine the actual yield level, i.e.how the improving biological potential is utilised.

Production efficiency, i.e. the use of labour and capital per hectare or animal, is exogenous in the base model and is given non-linear trends. The efficiency development of the representative farms in each region implicitly represents the investments to more efficient production techniques. In the base model there are also exogenous sunk costs during the first years of simulation starting in 1995. This represents sunk cost behaviour in the early years of the simulation and explains the increase of production in the ex post period 1995-1999. In the extended model with endogenous technical change of technology diffusion the efficiency development and the level of sunk costs each year is endogenous and depends on the endogenous investments and the exogenous depreciation rate.

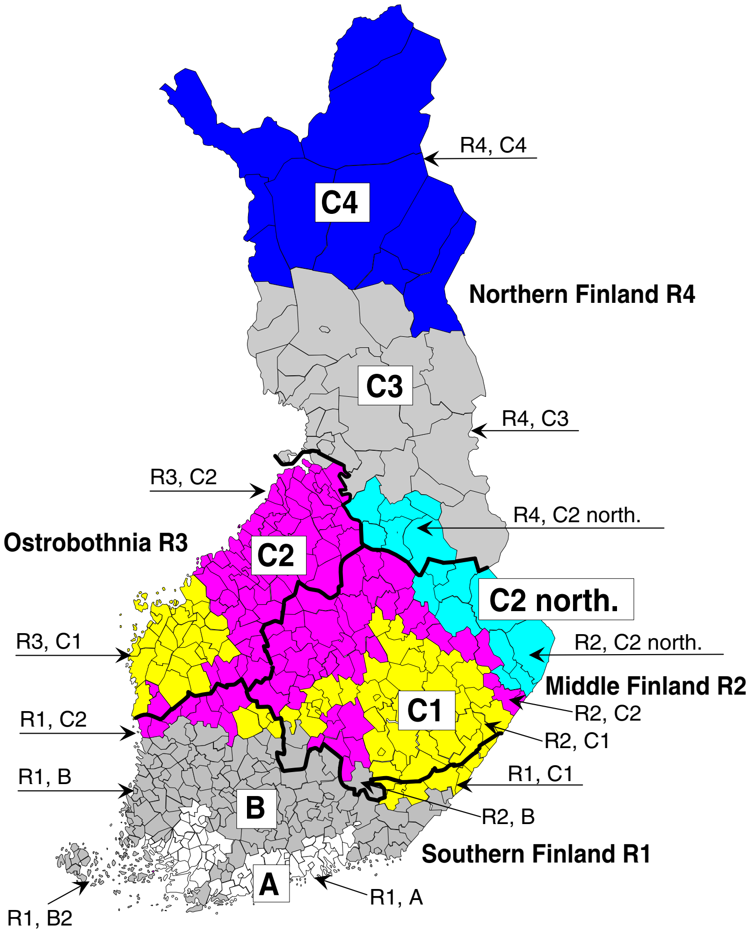

Figure 6.2. Main areas and support areas.

The study includes four main areas, Southern Finland, Central Finland, Ostrobothnia, and Northern Finland, and the production of these is further divided into sub-regions on the basis of the support areas (Figure 6.2). The food consumption and the feeding of animals are determined according to the main areas. The final and intermediate products move between the main areas at certain transportation cost. There is foreign trade from each main area at fixed average EU prices. The production in the main regions is further divided to sub-regions according to support areas. In total, there are 14 different production regions. This allows a detailed and regionally dis-aggregated description of policy measures and production technology.

The most important production lines of agriculture, like crop production, dairy production, the production of beef, pork and poultry meat, as well as egg production, are included. Arable crops include barley, oats, malting barley, mixed cereals, rye, wheat, oil-seed plants, sugar beets, potatoes for human consumption, starch potatoes, silage, green fodder, dry hay, and peas. The open and green set-aside areas are also included in the model. In the processing of sugar and milk, fixed margins in FIM are used between the raw material and the final product. Other products, like meat, eggs and cereals, are priced at the producer price level. The livestock includes dairy cows, sucker cows, dairy and suckler cow heifers, slaughter heifers separately from milk production and specialised beef production and, correspondingly, bulls of over one year and over 15 months, as well as sows and fattening pigs, laying hens, and other poultry.

6.3. Optimisation model

Competitive markets are simulated by maximising the total of the producer and consumer surplus. (*P*=price, *Q*=quantity supplied or demanded, *CS*=consumer surplus and *PS*=producer surplus in Figure 6.3). The constraints of the optimisation are the conditions concerning the market balance (demand-supply), production capacity, quotas, crop rotation, and other restrictions. Often there are certain fixed inputs and outputs corresponding to each production activity (Leontief technology). The outcome depends on the reactions of the demand and supply within the set framework, which also includes agricultural support. Agricultural policy measures are market interventions of the government, which influence the market balance and the consumer and producer surplus. As the final outcome the production and consumption in each region as well as the movements of products between the main areas under the assumption of perfect competition are obtained.

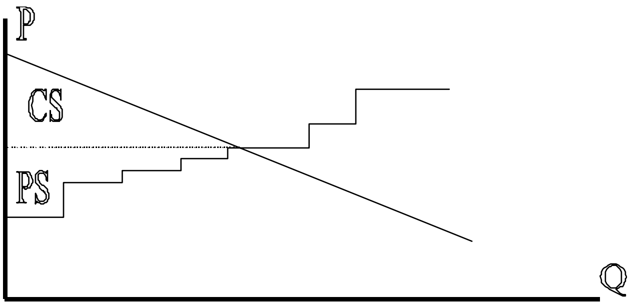

Figure 6.3. Consumer and producer surplus and the implicit supply curve given by the optimisation.

6.3.1. Derivation of the demand function

In some economic models it is assumed that small countries cannot influence the world market price level or the EU prices, which means that the prices of the foreign trade are fixed. When maximising consumer and producer surplus the domestic and the corresponding foreign product are fully homogeneous and the demand may shift in full either to the domestic or the foreign product as a result of a very small difference in prices. In such a case there cannot be imports and exports of the same product at the same time. If it is profitable to export a certain product, in the optimum outcome the whole country or a region may specialise very strongly in the production of certain products only. Such a strong specialisation is unrealistic, since there are many factors in reality which prevent or slow down excessive specialisation.

For the part of imports, in this study the problem has been solved by defining the domestic and the corresponding foreign product as different products, which may partly substitute for each other. At the same time there are both exports and imports of the same commodity. The demand functions of the domestic and foreign product influence each other through the elasticity of substitution. This type of approach has been frequently used in general equilibrium models, but not as frequently in partial equilibrium models maximising consumer and producer surplus. The substitutability and the sensitivity of the reactions of the foreign trade depend on the elasticities of substitution.

The derivation of the demand function presented here follows the main lines of derivation presented by Dixit (1988) and Sheldon (1992). However, Dixit (1988) and Sheldon (1992) do not present a detailed derivation as is presented here. As already noted in chapter 6.2 the demand functions are used in order to model the substitution mechanism between the domestic and imported products, not the total consumption of each food item. This is also a reason why income is not included in the demand function.

Let the utility function of a representative consumer be (6.1). Let Q_1 be the demand of domestic product and Q_2 the demand of the corresponding imported product. P_1 and P_2 are the prices of domestic and imported products, respectively. Parameters a_1, a_2, b_1, b_2 and k are all positive. The total consumption of each food product ($Q_1 + Q_2$) is given upper and lower bounds, i.e. the total consumption of each food item is constrained to a neighbourhood of an exogenous consumption trend. Hence, the upper bound is given for the total consumption of each food product, not to Q_1 or Q_2 separately. In neo-classical theory of consumer behavious the demand functions are obtained when the utility function (6.1) (summed over all products) is maximised relative to budget constraint (6.2), i.e. the money available for all food purchases E which is considered exogenous.

$$U(Q_1,Q_2)=a_1Q_1+a_2Q_2-\tfrac{1}{2}(b_1Q_1^2+b_2Q_2^2+2kQ_1Q_2) \tag{6.1}$$

$$\sum_{products} P_1Q_1+P_2Q_2 \leq E \tag{6.2}$$

In this study, however, the explicit income constraint can be removed since the total consumption of each food stuff is constrained very close to a given trend value. When domestic products and imports are imperfect substitutes and the prices of domestic and imported products are close to each other, the part of consumer income spent on the specific food items included into the DREMFIA model changes only little what ever combination of Q_1 and Q_2 is used in satisfying the total demand $Q_1 + Q_2$ constrained to a close neighbourhood of a given trend value.

Differentiating (6.1) with respect to Q_1 and Q_2, the inverse demand functions (6.3) and (6.4) are obtained. All parameters in equations (6.1-6.4) are positive and the utility function (6.1) is strictly concave. In addition, $(B_1B_2 - K^2) > 0$, when domestic and imported products are imperfect substitutes.

The inverse demand functions are (6.5) and (6.6).

$$Q_1=A_1-B_1P_1+KP_2 \tag{6.3}$$

$$Q_2=A_2+KP_1-B_2P_2 \tag{6.4}$$

$$P_1=a_1-b_1Q_1-kQ_2 \tag{6.5}$$

$$P_2=a_2-kQ_1-b_2Q_2 \tag{6.6}$$

The parameters of the inverse demand functions can be expressed as (6.7).

$$(6.7)\qquad a_1=\frac{A_1B_2+KA_2}{B_1B_2-K^2};\ a_2=\frac{A_2B_1+KA_1}{B_1B_2-K^2};\ b_1=\frac{B_2}{B_1B_2-K^2};$$

$$b_2=\frac{B_1}{B_1B_2-K^2};\ k=\frac{K}{B_1B_2-K^2}$$

In systems given by (6.3) and (6.4) and by (6.5) and (6.6) there are two equations and five unknowns in each, so additional conditions have to be defined in order to find the unknowns. Two more equations are obtained when the total price elasticity of the product (6.8) as well as

$$(6.8)\qquad \varepsilon=\frac{-(B_1P_1^2+B_2P_2^2-2KP_1P_2)}{E}=\frac{E_1}{E}(\varepsilon_{11}+\varepsilon_{12})+\frac{E_2}{E}(\varepsilon_{22}+\varepsilon_{21})$$

$$(6.9)\qquad E=E_1+E_2=P_1Q_1+P_2Q_2$$

the substitution elasticity between domestic and foreign product (6.11) are defined. The total price elasticity is the effect of an equiproportionate change in the price of domestic and imported product on the consumer expenditure E (defined in 6.9). E is the total amount of money consumed for each product. $E_1=P_1Q_1$ is the value of domestic products and $E_2=P_2Q_2$ is the value of corresponding imported products. ε_{ij} is the price elasticity of demand of product i subject to the price of product j.

$$(6.10)\qquad \varepsilon_{ij}=\frac{dQ_i}{dP_j}\frac{P_j}{Q_i}\qquad i=1,2:\ j=1,2$$

Substitution elasticity between domestic and imported product is defined as (6.11). To be able to calculate an algebraic presentation for substitution elasticity, one has to express Q_1/Q_2 as a function of P_1/P_2. Let us show how this can be done.

Assume that consumers' incomes change. The consumption of products also changes. Assume that the utility function (6.1) is homothetic. This means that the utility function (6.1) is monotonously increasing subject to Q_1 and Q_2 in a neighbourhood of the initial values of Q_1 and Q_2 i.e. the representative consumer is not satiated[3]. By the homotheticity of the utility function, the consumption of all products changes by the same fraction, say *r*. In particular $Q_1' = rQ_1^*$ and $Q_2' = rQ_2^*$, where Q_1^* (Q_2^*) stands for the initial level of the consumption of the domestic (imported) product.

(6.11)
$$\sigma = -\frac{dlog(\frac{Q_1}{Q_2})}{dlog(\frac{P_1}{P_2})} = \frac{(\frac{P_1}{P_2})\, d\,(\frac{Q_1}{Q_2})}{(\frac{Q_1}{Q_2})\, d\,(\frac{P_1}{P_2})}$$

(6.12)
$$\frac{P_1^*}{P_2^*} = \frac{a_1 - b_1 rQ_1^* - krQ_2^*}{a_2 - b_2 rQ_2^* - krQ_1^*}$$

Such a proportional change corresponds to a ray starting at the origin and passing through the initial point W(Q_1^*, Q_2^*). See Figure A-1 in Appendix. It depicts an equiutility curve between the domestic and the imported product. The homotheticity assumption implies that the slope of the equiutility curve (that is, dQ_2/dQ_1) remains constant when incomes change. That is, the slope remains constant along the ray originating at (0,0). This means that P_1/P_2 remains constant on this line because $dQ_2/dQ_1 = - P_1/P_2$. Thus one can write (6.12). Substituting (6.3) and (6.4) into (6.12) one obtains (6.13) and (6.14) or $P_1^* a_2 = P_2^* a_1$.

(6.13)
$$\frac{P_1^*}{P_2^*} = \frac{\frac{a_1}{r} - b_1 Q_1^* - kQ_2^* + a_1 - a_1}{\frac{a_2}{r} - b_2 Q_2^* - kQ_1^* + a_2 - a_2} = \frac{P_1^* - (1 - \frac{1}{r})a_1}{P_2^* - (1 - \frac{1}{r})a_2}$$

Taking into account expressions (6.7) for a_1 and a_2 one gets (6.13). The parameters A_1 and A_2 in equations (6.3) and (6.4) are linearly proportional to the initial consumption level. This means that when adjusting A_1 and A_2 in equal proportion one always stays on the ray $Q_2 = Q_1\, A_2/A_1$ (now $r = A_2/A_1$), which connects origin and point W. Thus, the parameters A_1 and A_2

(6.14)
$$P_1^*(A_1 K + A_2 B_1) = P_2^*(A_2 K + A_1 B_2).$$

---

[3] This means that the first derivatives of (6.1) subject to Q_1 and Q_2 are increasing in the neighbourhood of the initial consumption bundle. This implies that $a_1 > b_1Q_1 - kQ_2$ and $a_2 > b_2Q_2 - kQ_1$.

do not affect the substitution elasticity. For example, when reducing the consumption of the domestic product by A_1 and the consumption of the imported product by A_2 one ends up at point $W'(Q'_1, Q'_2)$ (see Figure A-1) where the demand functions can be written as (6.15) and (6.16).

$$Q_1' = -B_1 P_1 + KP_2 \tag{6.15}$$

$$Q_2' = KP_1 - B_2 P_2 \tag{6.16}$$

The relation Q'_1/Q'_2 can be expressed as a function of P_1/P_2 as presented in (6.17). When differentiating (6.17) with respect to P_1/P_2 one obtains the expression (6.18).

$$\frac{Q_1'}{Q_2'} = \frac{\frac{Q_1'}{P_2}}{\frac{Q_2'}{P_2}} = \frac{-B_1(\frac{P_1}{P_2}) + K}{K(\frac{P_1}{P_2}) - B_2} \tag{6.17}$$

$$\frac{d(\frac{Q_1'}{Q_2'})}{d(\frac{P_1}{P_2})} = \frac{-B_1(K\frac{P_1}{P_2} - B_2) - K(-B_1\frac{P_1}{P_2} + K)}{(K\frac{P_1}{P_2} - B_2)^2} = \frac{B_1B_2 - K^2}{(K\frac{P_1}{P_2} - B_2)^2} \tag{6.18}$$

Incorporating this expression to equation (6.10) and using equations (6.15-6.16) one obtains, after some basic algebraic manipulation, the following expression (6.19) for the substitution elasticity.

$$\sigma = \frac{\frac{P_1}{P_2}(B_1B_2 - K^2)}{(B_1\frac{P_1}{P_2} - K)(B_2 - K\frac{P_1}{P_2})} \tag{6.19}$$

Given initial values for consumption, prices as well as the total price elasticity and the substitution elasticity, one can calculate the parameters of the demand system (6.3) and (6.4) using equations (6.5), (6.6), (6.8), (6.13) and (6.19). After some algebraic manipulation one obtains the expressions (6.20) and (6.21). Dixit (1988) and Sheldon (1992) calculated the same expressions.

$$A_1 = Q_1^*(1-\varepsilon); A_2 = Q_2^*(1-\varepsilon); K = -\varepsilon\frac{Q_1^* Q_2^*(\sigma - 1)}{P_1^* Q_1^* + P_2^* Q_2^*} \tag{6.20}$$

$$B_1 = -\varepsilon\frac{Q_1^*(P_1^* Q_1^* + P_2^* Q_2^* \sigma)}{P_1^*(P_1^* Q_1^* + P_2^* Q_2^*)}; B_2 = -\varepsilon\frac{Q_2^*(P_1^* Q_1^* \sigma + P_2^* Q_2^*)}{P_2^*(P_1^* Q_1^* + P_2^* Q_2^*)} \tag{6.21}$$

A substitution elasticity approaching infinity means that domestic and corresponding imported products are perfect substitutes. In that case, products are identical, and any difference in price, however small, between the products is a sufficient incentive for consumers to shift totally to the cheaper product. In reality, however, domestic and corresponding imported products are most often imperfect substitutes. If the substitution elasticity is 1, parameter k in (6.5) and (6.6) is zero and domestic and imported products are then totally different products. If substitution elasticity were smaller than 1, the k-parameter is negative, which means that utility function would be no longer concave. Thus, the substitution elasticity must be greater than 1. The greater the substitution elasticity, the more similar are the products.

Values for the substitution elasticities may be obtained either from market data or as guess values from experts. Substitution elasticity for beef, for example, is given relatively low values (close to 1). Consumers are suspicious about the quality of imported beef and they are highly reluctant to change to imported beef (Lihatalous 2/2001, p. 44). Some cereals and sugar, however, are mostly intermediate products used by food industry, and the domestic and the imported products can be regarded quite homogenous. Hence, the substitution elasticity of sugar and some cereals are given relatively higher values than for beef (clearly higher than 1).

6.3.2. Objective function

Objective function (6.24) is of the second degree; i.e. price is an endogenous variable. The hypothesis is that efficient markets under perfect competition operate in an optimal way in terms of producer and consumer surplus. This is required in order to make the price of the product equal to the marginal cost of the production. Thus the task of the optimisation is to simulate the market (Hazell and Norton 1986, p. 160-162, 167-168; Silberberg 1990, p. 492-493. P.A. Samuelson (Samuelson 1952, 1983), who was the first to formulate the markets into an optimisation problem restricted to equilibrium, did not set any strict assumptions on the behaviour of the producer or the degree of competition. The only requirements are that an individual producer or consumer cannot alone influence the prices and that he is profit maximising. In addition, he may avoid risk and appreciate other than economic factors, too. The closer the reality is to the basic assumptions of perfect competition and neo-classical consumer theory, the better the markets according to the optimisation model correspond to the reality (Hazell and Norton, p. 161-162).

In the following upper case letters denote variables. Lower case letters denotes parameters and sets. The sets are as follows:

g	regions (r pcs),
b	sub-regions (s_r),
i	products (n),
k	production inputs (m),
l	fixed production-inputs (q),
z	intermediate products (n_r),
j	production activities (animal categories and crops) (s) and
f	feedstuffs (nf).

The variables and parameters are as follows:

$a1_{gi}$	parameter a_1 (intercept of the inverse demand function 6.3) of domestic product i in region g,
$a2_{gi}$	parameter a_2 (intercept of the inverse demand function 6.4) of imported product i in region g,
$Q1_{gi}$	consumption of domestic food product i in region g,
$Q2_{gi}$	consumption of imported food product i in region g,
$P1_{gi}$	price of domestic product i in region g,
$P2_{gi}$	price of imported product i in region g,
Z_{gk}	use of input k on region g,
V_{gz}	use of intermediate product z in region g,
w_{gz}	price of intermediate product z in region g,
T_{ghi}	transport of product i from area g to area h,
t_{ghi}	unit transportation cost of product i from area g to area h,
$c1_{gk}$	and $c2_{gk}$ parameters of supply function for input k in region g,
$c1_{gk}$	fixed price of input k in region g (unless supply functions of inputs are defined),
X_{gbj}	level of production activity j in sub-region b of region g,
F_{gfj}	amount of feedstuff f given for animal j in main region g
fu_f	energy content coefficients of feeds f and
$funits_j$	fodder units required by animal j.
e_{gbij}	is the yield coefficient of production activity j when producing product i in sub-region b in region g
u_{gbkj}	the amount of input k required by the production activity j in sub-region b in region g

S_{bj}	support paid for production activity *j* in support region *b,*
E_{gi}	export of product *i* from region *g,*
ER_{gz}	export of intermediate product *z* from region *g,*
I_{gi}	import of product *i* to region *g* (=$Q2_{gi}$),
IR_{gz}	import of intermediate product *z* to region *g*,
ep_{i}	price of product *i* in the EU,
erp_z	price of the intermediate product *z* in the EU,
EXC_{gi}	export cost of product *i* from region *g*,
EXC_{gz}	export cost of the intermediate product *z* from region *g*
ftc_i	foreign trade cost of product *i*
ftc_z	foreign trade cost of intermediate product *i*
$INTR_{gi}$	intervention flow of product *i* from region *g*
npr_i	intervention price of product *i*
$PROC_{gi}$	processing activity of product *i* in region *g*
pc_i	processing cost of product *i*

Consumer surplus (*CS*) in (6.22) and surpluses of the processing industry and producers are obtained by adding up surpluses of products in different regions. The producer surplus can be divided to the surplus of the processing industry (PS_1) and to farmer's surplus (PS_2).

$$CS = \sum_{g=1}^{r} \sum_{i=1}^{n} [(a1_{gi}Q1_{gi} + a2_{gi}Q2_{gi} - 0.5b1_{gi}Q1_{gi}^2 - 0.5b2_{gi}Q2_{gi}^2 - 2k\,Q1_{gi}Q2_{gi}) - P1_{gi}Q1_{gi} - P2_{gi}Q2_{gi}] \tag{6.22}$$

$$\begin{aligned} PS_1 = \sum_{g=1}^{r} [& \sum_{i=1}^{n} P1_{gi}Q1_{gi} + P2_{gi}Q2_{gi} - \sum_{z=1}^{n_r} V_{gz}w_{gz} - \sum_{i=1}^{n} PROC_{gi}\,pc_i \\ & - \sum_{i=1}^{n} \sum_{h=1}^{r} t_{ghi}T_{ghi} + \sum_{i=1}^{n} npr_i INTR_{gi} + \sum_{i=1}^{n} (E_{gi} - I_{gi})ep_i \\ & + \sum_{z=1}^{n_r} (ER_{gz} - IR_{gz})erp_z - \sum_{i=1}^{n} (I_{gi}ftc_i + E_{gi}EXC_{gi}) \\ & - \sum_{z=1}^{n_r} (IR_{gz}ftc_z + ER_{gz}EXC_{zi})] \end{aligned} \tag{6.23}$$

$$PS_2 = \sum_{g=1}^{r} \sum_{z=1}^{n_r} V_{gz}w_{gz} - \sum_{g=1}^{r} \sum_{k=1}^{m} (c1_{gk}Z_{gk} + 0.5c2_{gk}Z_{gk}^2) + \sum_{g=1}^{r} \sum_{j=1}^{s} \sum_{b=1}^{sr} X_{gbj}\;S_{bj} \tag{6.24}$$

$$
\begin{aligned}
TS = \sum_{h=1}^{r} [\sum_{i=1}^{n} (a1_{gi}Q1_{gi} + a2_{gi}Q2_{gi} - 0.5b1_{gi}Q1_{gi}^{2} - 0.5b2_{gi}Q2_{gi}^{2} - kQ1_{gi}Q2_{gi}) \\
- \sum_{k=1}^{m} (c1_{gk}Z_{gk} + 0.5c2_{gk}Z_{gk}^{2}) + \sum_{b=1}^{sr}\sum_{j=1}^{s} X_{gbj}S_{bj} - \sum_{i=1}^{n} PROC_{gi}pc_{i} \\
- \sum_{h=1}^{r}\sum_{i=1}^{n} t_{ghi}T_{ghi} + \sum_{i=1}^{n} INTR_{gi}npr_{i} + \sum_{i=1}^{n} (E_{gi} - I_{gi})ep_{i} \\
+ \sum_{z=1}^{nr} (ER_{gz} - IR_{gz})erp_{z} - \sum_{i=1}^{n} (I_{gi}ftc_{i} + E_{gi}EXC_{gi}) - \sum_{z=1}^{nr} (IR_{gz}ftc_{z} + ER_{gz}EXC_{zi})]
\end{aligned}
\tag{6.25}
$$

When all surpluses are added up, the total surplus of the agricultural sector (*TS*), which is to be maximised, is obtained. Food consumption, production, processing, transfers of products between regions, as well as import and export are the decision variables. Supports paid to farmers are exogenous parameters which are accounted for surpluses of the sector. Costs for taxpayers and connections to the other sectors of the economy are excluded. Support is basically paid according to the production activities, which are arable areas and numbers of animals. However, there are some price supports paid for farmers during the transition period 1995-1999. Some price supports still continue after 1999 in most parts of Finland. Price supports are gradually replaced by fixed per animal and per hectare payments during the transition period.

6.3.3. Constraints

The objective function is maximised so that the market clears in each region for each product. Equation (6.26a) is an equilibrium equation for domestic final products in different regions. The demand of the domestic product $Q1_{gi}$ can be satisfied only by domestic production, i.e. by production in the region *g* or by transfer from other regions. There may be several production activities producing $Q1_{gi}$. For example, beef can be obtained from bulls over 15 months old, bulls less than 15 months old, heifers, dairy cows and suckler cows. Dairy products and sugar are priced on the consumer price level in the model. In that case the demand for the domestic product *i* in region *g*, can be satisfied by the processing of product *i* in processing activities *j* in region *g* when X_{gbj} should be replaced by a corresponding processing activity. T_{ghi} is the transfer of products from region *g* to region *h*. E_{gi} is the export of product *i* from region *g* and I_{gz} is the import of intermediate product *z* to region *g*. The demand of the foreign product $Q2_{gi}$ can be satisfied only by imports. Inequalities (there has to be at least as much supply as demand in each region) are formed for both domestic and foreign products.

$$Q1_{gi} - \sum_{b=1}^{sr} \sum_{j=1}^{s} e_{gbij} X_{gbj} - \sum_{h=1}^{r} T_{hgi} + \sum_{h=1}^{r} T_{ghi} + E_{gi} \leq 0 \tag{6.26a}$$

$$g = 1 \ldots r, i = 1 \ldots n$$

Balance equations are formed separately for final and intermediate products (6.26b). The balance equations ensure that the demand of the final products and intermediate products are satisfied. In the case of intermediate products, like raw milk or raw sugar used by food industry, $Q1_g$ in the equation (6.26a) is replaced by a regional processing activity $PROC_{gi}$. Intermediate products and inputs used by industry may be either imported or exported, i.e. intermediate domestic products are assumed to be homogenous with the imported ones. Production of raw materials may include yield coefficients e_{gbij} which have to be taken into account. In equation (6.26b) the same raw materials or intermediate products may be used in different processing activities which require different input combinations (denoted by v_{zi}). For example, different milk products consist of different combinations of skimmed milk and milk fat. The balance equations like (6.26b) ensure that there is enough skimmed milk and milk fat for processing in each region. Skimmed milk and milk fat as well as the final dairy products can also be transported between the main regions.

$$\sum_{i=1}^{n} v_{zi} PROC_{gi} - \sum_{b=1}^{sr} \sum_{j=1}^{s} e_{gbij} X_{gbj} - \sum_{h=1}^{r} T_{hgz} + \sum_{h=1}^{r} T_{ghz} + \tag{6.26b}$$

$$ER_{gz} - IR_{gz} \leq 0 \quad g = 1 \ldots r, z = 1 \ldots n_r$$

Inputs needed for each production activity are, in many cases, fixed in the model (Leontief-technology). Use of feedstuffs per animal, however, may change endogenously. Use of each feed stuff per animal per year is a decision variable (F_{gjf}) in each main region. This means that the use of each feed stuff (f) of each animal (j) may change in each main region (g). In total, there are 420 variables representing the feed use of animals in the model. Required energy, protein and roughage content of feeding can be fulfilled using different feeding alternatives. There are specific equations representing the feed requirements. The need for energy of each animal ($funits_j$) is ensured by equation (6.27). Similar linear equations are also constructed for protein and roughage needs of different animals.

$$\text{(6.27)} \qquad \sum_{f=1}^{nf} F_{gjf} \, fu_f \geq funits_j$$

Equation (6.27) means that the balance equation for feedstuffs (6.28) becomes non-linear. In equation (6.28) SF_{gf} denotes production of feedstuff f on region g. The total amount of feedstuff f needed in region g is given by the sum of all animals weighted by their consumption of the feedstuff f. Feedstuffs may move between regions at certain transportation cost and they may be imported and exported. Domestic and imported feedstuffs are assumed to be homogenous.

$$\text{(6.28)} \qquad SF_{gf} - \sum_{b=1}^{sr} \sum_{j=1}^{s} X_{gbj} F_{gfj} + \sum_{h=1}^{r} T_{hgf} - \sum_{h=1}^{r} T_{ghf} - E_{gf} + I_{gf} \geq 0; g = 1 \ldots r; f = 1 \ldots nf$$

Equation (6.28) is non-linear, which increases the technical solution time of the model. Because of this the feeding is optimised for the part of the main areas only, not for each sub-region separately. The use of the different feedstuffs is allowed to change by only 5-10% from the preceding year. This is partly due to biological reasons as well as because certain fixed production factors are needed in the feeding of animals. Significant changes in the feeding occur only when the price relations in favour of the change are effective for long enough.

In the case of dairy cows there is a concave quadratic milk yield function which determines the increase of milk yield when grain is substituted for roughage. In equation (6.29) $yield_t$ is milk yield per dairy cow in year t, $yield_0$ is initial yield, *incr* is estimated annual yield increment (due to improvement in genetic production potential), F_{grain} is the use of each grain feed in feeding and w_{grain} is the weight of each grain in the production function (all grain-based feeds are not equally favourable in milk production). Parameters *a* and *b* are positive, but *c* is strictly negative, which means concavity of the production function.

$$\text{(6.29)} \qquad yield_t = yield_0 + t \times incr + a + b \sum_{grains} w_{grain} F_{grain} + c\left(\sum_{grains} w_{grain} F_{grain} \right)^2$$

Thus, when increasing grain in the feeding of dairy cows, the milk yield increases. However, because of concavity of (6.29) the resulting increase of milk yield becomes smaller the greater the initial amount of grain used in feeding is. Consequently, in the case of dairy cows, the term $\partial^2 yield / \partial (F_{gfj})^2$ is negative, which means that the increase in profit becomes smaller the higher the initial share of grain based feed stuffs in the feeding of dairy cows is.

Equation (6.29) does not bring any computational problems. The maximum of the optimisation model is always unique. This can be shown easily using the Lagrangian function. The Lagrangian of the problem (here only part of the constraints, relevant in calculating the Hessian, is written), can be written as (6.30).

$$
\begin{aligned}
L = {} & \sum_{g=1}^{r}\sum_{b=1}^{sr}\sum_{j=1}^{s}[X^a_{gbj} \times yield \times p_m - X^a_{gbj}\sum_{f=1}^{nf} F_{gfj} \times p_f] - \\
& \sum_{g=1}^{r}\sum_{j=1}^{s}[\lambda_{1jg}(\sum_{f=1}^{nf} F_{gfj} fu_f - funits_j) - \lambda_{2jg}(\sum_{rf=1}^{nrf} F_{gfj} fr_{rf} - rough_j) \\
& - \lambda_{3jg}(\sum_{f=1}^{nf} F_{gfj} fp_f - prot_j)] - \sum_{g=1}^{r}\sum_{f=1}^{nf}\lambda_{4fg}(\sum_{b=1}^{sr} e_{gbf} X^h_{gbf} - \\
& \sum_{b=1}^{sr}\sum_{j=1}^{s} X^a_{gbj} F_{gfj} + \sum_{h=1}^{r} T_{hgf} + \sum_{h=1}^{r} T_{ghf} - E_{gf} + I_{gf})
\end{aligned}
\tag{6.30}
$$

X^h_{gbf} is the number of hectares of feed crop *f* in sub-region *b* in main region *g* and X^a_{gbj} is the number of animals *j* in sub-region *b* in main region *g*. p_f is the price of feed stuff *f* and p_m is the price of an animal product (like meat and milk). *yield* denotes the animal yields. e_{gbf} is the yield per hectare of feed crop *f* in sub-region *b* in region *g*. fr_{rf} is the dry matter content in feedstuff *rf* and $prot_f$ is the protein content in feedstuff *f*. The roughage constraint concerns only bovine animals and the protein constraint concerns only pigs and sows in the model. λ_{1jg}, λ_{2jg}, and λ_{3jg}, are the Lagrange multipliers of the energy (measured in fodder units), roughage and protein constraints respectively. λ_{4jg} are the Lagrange multipliers of the balance equation (6.28).

Maximising the Lagrangian is equivalent to maximising the objective function (6.25) subject to the constraints described. It has been already stated that the parameters of the utility function of consumers' are positive and thus the utility function is strictly concave. The change in the feeding of animals also results in a concave Lagrangian. Calculating the second derivatives of the Lagrangian one can readily see that the second derivatives $\partial^2/\partial (X^a_{gbj})^2$ and $\partial^2 L/\partial (F_{gfj})^2$ are zero for all animals except dairy cows. $\partial^2 L/\partial (F_{gfj})^2$ is negative in the case of dairy cows because of the concavity of the milk yield function. What remains are the derivatives $\partial^2 L/\partial F_{gfj}\partial X^a_{gbj}$ and $\partial^2 L/\partial X^a_{gbj}\partial F_{gfj}$. According to Young's theorem, however, these derivatives are equal. Hence, the determinant of the Hessian of the Lagrangian function is always negative.

$$(6.31)\qquad \begin{vmatrix} \frac{\partial^2 L}{\partial X^2} & \frac{\partial^2 L}{\partial X \partial F} \\ \frac{\partial^2 L}{\partial F \partial X} & \frac{\partial^2 L}{\partial F^2} \end{vmatrix} = -[\frac{\partial^2 L}{\partial X \partial F}]^2 < 0$$

The Hessian matrix is thus negative definite and the Lagrangian (6.30) is concave (Varian 1992, p. 493-502) with respect to the feeding variables. The fact that $\partial^2 L / \partial (F_{gfj})^2$ is zero (or negative in the case of dairy cows) implies that profits increase at a constant rate (or at a decreasing rate in the case of dairy cows) when the use of feedstuffs changes to more economical direction. Given the annual lower and upper bounds imposed on the feeding variables, the maximum of the optimisation problem is always unique.

The model always changes feeding towards more economical direction in terms of prices of final products, inputs and subsidies. Change in the use of feedstuffs is an important adjustment mechanism that helps farmers to survive in changing economic conditions. These changes may have great effects on land use and profitability of agricultural production.

Crop and animal yield levels and other production costs of feedstuffs are different in different regions. Most feed stuffs, excluding silage and grass can be transported between the regions. The transportation costs also influence the most economic feedstuff combination in different regions. Feedstuff production and use of feed are dependent on each other. Because of different agricultural supports paid for feed crops, like extensification premia and CAP-supports for silage (which were granted to Finland in the Agenda 2000 agreement), for example, it is not always trivial to forecast the change in feeding in different regions without running the model.

Clearly, the model outcome is dependent on the short-term restrictions imposed on the rate of change in feeding. The restrictions are different for pigs, bulls and dairy cows, respectively. The physiology of dairy cows and other bovine animal does not allow rapid changes in the use of feedstuffs, even if energy, protein and roughage intakes are fulfilled. The changes in diet of pigs may be greater, but there are only few reasonable alternatives how to change feeding in pig farming. There are also technical factors and sunk costs that prevent rapid changes in feeding. Due to sunk costs only a fraction of farmers are able to make rapid changes in feeding annually. Thus, the short-term restrictions on the rate of change in feeding are reasonable in modelling dynamics of the agricultural sector. In the long term, however, changes in feeding are likely to happen if there are any changes in relative prices of inputs and outputs. Endogenous feed use influences land allocation and makes the model react more realistically to changes in prices and supports.

In equation (6.32) regional production and processing activities require certain fixed quantities of inputs. u_{gbkj} is the input k required by the production activity j in sub-region b in region g. Inputs are not traded in foreign trade, nor do they move from a region to another. It is assumed that any amount of a variable input is available at a fixed price.

$$(6.32) \qquad \sum_{b=1}^{sr} \sum_{j=1}^{s} u_{gbkj} X_{gbj} - Z_{gk} \leq 0 \quad g = 1 \ldots r,\ k = 1 \ldots m$$

Equation (6.33) sets limits for production activities through fixed inputs. M_{gl} is the maximum for fixed resources l in region g and w_{glj} is the quantity of fixed input 1 required by the production activity j in region g. In the case of agricultural production the only limit for fixed inputs is maximum area in each region. Some upper limits are set for regional milk processing capacities.

$$(6.33) \qquad \sum_{j=1}^{s} w_{glj} X_{gj} \leq M_{gl};\ g = 1..r;\ l = 1..q$$

All variables are non-negative. $T_{hi} = 0$ when $g=h$, i.e. the model does not take transportation costs within the areas into account.

Restrictions are imposed for the production variables based on the productio of the previous year. W_l represents the lower bound and W_u represents the upper bound in equation (6.34). The restrictions represent short-term technical and biological constraints in each production line. Crop areas may change faster than the number of animals.

$$(6.34) \qquad (1 - W_l) X_{gbj}(t-1) \leq X_{gbj}(t) \leq (1 + W_u) X_{gbj}(t-1)$$

In the ame way as the number of animals, the use of feedstuffs may change only gradually over time due to fixed production factors in the production and handling of feedstuffs. As already mentioned in chapters 6.2 and 6.3 the total food consumption (domestic and imported food combined) of each food item are given upper and lower bounds from the exogenously given trend value.

6.3.4. Exports

It has been noted above that the domestic and corresponding foreign products have been defined as different products. However, the export products are still homogeneous with the domestic products. It is possible that the exports of certain products may decline too rapidly or grow too fast without the frictions of exports to be modelled separately. In reality exports cannot grow too rapidly in the short term without considerable additional costs. Instead, if the support policy or other factors are in favour of the export of a certain product for an adequately long time, exports may grow significantly over time. In that case the export costs remain at a reasonable level.

In this study export costs have been modelled as linearly increasing in relation to the export quantities of the preceding year (Figure A-2 in Appendix). The linear export cost function (6.35) is calibrated every year to the last year's level of exports.

$$EXC_{gi} = ftc_i + ftc_i k_e \frac{E_{gi}(t) - E_{gi}(t-1)}{E_{gi}(t-1)} \quad \text{if } E_{gi}(t-1) > 0 \tag{6.35}$$

$$EXC_{gi} = ftc_i \quad \text{if } E_{gi}(t-1) = 0 \tag{6.36}$$

Either (6.35) or (6.36) is chosen before each optimisation on the basis of the eports of the previous year $E_{gi}(t-1)$. This definition of the export cost function also means that the export costs remain constant if the export quantity does not change from the preceding year. On the other hand, the export costs decrease if the export quantities fall from the previous year. For this reason, parameter k_e in equation (6.35) is non-negative but lower than 1. It is assumed that the exports and imports cannot influence the price level of the EU. The change in the export costs is considered to result from marketing costs, transportation arrangements, and other similar costs. These costs are only a fraction, less than 10%, of the price of the product. The definition of export costs in equations (6.35) and (6.36) is mainly a technical measure to prevent sensitivity to small changes in the EU price level. Parameter k_e has been used for calibration, i.e. minor changes have been made in k_e to replicate the known exports at some base year. For most products this simple definition of export costs works well.

6.4. Development of crop levels and average yields of animals

The crop level of the different crops is determined separately for each year and for the 14 production regions. The crop levels are obtained by determining the optimum fertilisation at the farm level using equation (6.37).

$$\frac{dF(N)}{dN} = \frac{P_f}{P_c} \tag{6.37}$$

F(N) is the fertilisation response function in terms of nitrogen, P_f is the price of nitrogen (exogenous in the model), and P_c the price of the crop product (endogenous in the model). Crop prices P_c are market prices of the previous year, or, in the case of a policy change, EU intervention prices.

As the fertilisation response function, the Mitscherlich function (6.38)

$$F_m(N) = m(1 - ke^{-bN}) \tag{6.38}$$

where *F* is yield per hectare, *N* is nitrogen use per hectare and *m, k* and *b* are the parameters, is used for barley, malting barley, wheat, oats, mixed cereals and peas. The quadratic function (6.39) is used for rye, potatoes, sugar beet, hay, silage, green fodder and oilseeds.

$$F_q(N) = a + bN + cN^2 \tag{6.39}$$

The Mitscherlich function was preferred to the quadratic function since the quadratic function results in quite small changes in the nitrogen fertilisation and crop yield levels even in the case of large changes in the price relation between the fertiliser price and crop price. This was also noted by Ylätalo (ed.) (1996, p. 64-65). According to Ylätalo (ed), the change in relative prices of fertilisers and crops due to the EU membership would result in a 11% decrease of fertilisation of wheat when a quadratic response function were used, while the Mitscherlich function would result in a 22% decrease in the fertilisation of wheat. These changes in fertilisation, in turn, would lead to a decrease of crop yield by 2.5% in the case of the quadratic function, and to a 4.8% decrease of crop yield level in the case of the Mitscherlich function.

There are no significant differences in the fit of quadratic or Mitscherlich functions to the actual observations from the fertilisation trials. Hence, there are no statistical reasons in favour of the Mitscherlich function. Either of these functions could be chosen. In this study, however, it was concluded that the use of Mitscherlich function is more appropriate than the use of quadratic function. Using quadratic response functions could undermine the actual response of farmers. The costs of crop production are relatively high in Finland compared to most other EU countries, and the reduced prices are likely to result in decreased use of inputs, not only fertilisers, in crop cultivation. Hence, one expects some response to changed price relations in crop production.

There have been fears that further price reductions and increased direct subsidies per hectare due to Agenda 2000 would lead to extreme cost minimisation in order to maximise profits, and to very low yield levels (Ylätalo et al. 1996, p. 31-32, 68-71). Since response functions between crop yield and the use of other inputs are very difficult to specify (few, if any, other experiments but only those concerning the fertiliser response are conducted in Finland), the fertiliser response function is the only mechanism affecting the intensity of production in the model. On the basis of a priori information and expectations of agricultural experts, this mechanism should not be negligible. Hence, it was concluded that the fertilisation response provided by Mitscherlich function would represent a more realistic production response than the quadratic function. The Mitscherlich function could not be used in all cases, however, since it had not been estimated for all crops.

The relative slope of the rise of the functions as the use of nitrogen grows is obtained from the fertilisation response functions estimated from Finnish fertilisation experiments (parameter of the first degree *b* in the case of the quadratic function and exponential parameter *b* for the Mitscherlich function). The other parameters of the fertilisation response function in the different regions are obtained by assuming the current level of nitrogen fertilisation as the optimum at the chosen functions and at current prices. This is necessary in order to adjust the crop yield functions to regional production conditions. Thus the other parameters of functions (6.38) and (6.39) are not exactly the same as reported by the different fertilisation trials. The slope of the "average" crop yield function decreases at a faster rate when increasing the nitrogen fertilisation than the slope in the original estimated functions. However, given a certain change in the price relation of crop products and fertilisation the resulting optimal nitrogen fertilisation level results in the same changes in the crop yield level, in relative terms.

This is not to say that the actual biological crop yield function would be identical to the "average" yield functions in the model. The known fertilisation and crop levels are possibly affected by a number of reasons, not only the biological ones. Production conditions and soil qualities may differ considerably even at the same farm. One may, however, incorporate all the factors affecting the fertilisation into parameters *a* and *c*, in the case of the quadratic function, and into parameters *m* and *k*, in the case of the Mitscherlich function.

The parameters of the crop yield functions are kept constant, except the parameters *m* (in 6.38) and *a* (in 6.39) which are increased annually by a constant increment, throughout the simulation period 1995-2010. This means that the relative response to nitrogen fertilisation is unchanged. Such an assumption is vulnerable, since the genetic yield potential and the response to fertilisation may change as a result of the biological research. There are little, if any empirical data available for estimating the changes in the parameters affecting the fertilisation response over time in Finland. Furthermore, some studies of fertilisation response also assume constant response over a number of years. For example, Heikkilä (1980, p. 21) assumed that only fertilisation affects the crop levels. Empirical information from several years was used in order to eliminate various random factors affecting the response function to be estimated (Heikkilä 1980, p. 19). Also Kleemola (1989) estimates crop yield functions using only fertilisation levels as explanatory variables. In the study of Bäckman et al. (1997) different crop varieties were used in the trials and some dummy variables were used in order to cover the effect of the different plant varieties. Such practice, however, was applied only for a subset of crops. In the study of Ylätalo (ed.) (1996), from which part of the parameter estimates have been obtained into this study, the crop yield functions have been estimated without the dummies.

Modelling the development in the values of parameters influencing the nitrogen response requires a lot of work and additional trials since the dummy variable approach, or some other way of modelling, has not been applied for all crops. There are also difficulties in such modelling. Because of various random factors the appropriate methodology to include annual variations in the crop yields is not the same for all crops. According to Sumelius (1993), different dummies are needed for each crop in order to appropriately model annual variations in crop yields. Hence, due to the lack of data and difficulties in modelling the development of nitrogen response, the parameters of the crop yield functions influencing the fertilisation response are kept constant in this study. The fertilisation response functions for the 14 different production regions are set at the average level indicated by the time series of regional average crop yield levels of the past 11 years.

Independent of the fertilisation level, the response function will rise linearly at a given trend. A very modest yield increase trend – or no increase at all – is assumed in the practical applications of the model described in Chapter 8. The crop yield level is thus partly exogenous and partly endogenous in the model.

The scalar parameter of the milk yield function (6.29) grows linearly in all regions. The milk yield per cow per year is slightly different in different regions. There is a coefficient in the model which determines the increasing feeding requirements due to the increased potential in milk yield. The reason for including such a coefficient is that the increase in the yield potential increases the feeding requirements only slightly, i.e. dairy cows are able to utilise the fodder more efficiently when the milk yield level goes up.

The actual milk yield, however, is influenced by the feeding variables. Changes in the use of grain based feedstuffs influence the milk yields. Thus the yield of dairy cows is partly exogenous and partly endogenous in the model.

Egg yield per laying hen and the average number of piglets per sow are fully exogenous and grow linearly in all regions.

6.5. Investments, sunk costs and exogenous technical change in the base model

6.5.1. Investments and sunk costs

The increase in the production efficiency is exogenous in the base model while in the extended model it is endogenous. There are no endogenous investment activities in the base model. The decision variables in each optimisation model simulating the competitive markets include the number of hectares of crops and animals in each region. A certain depreciation or fixed cost is assigned to the production activities per hectare or per animal. Thus the production activities already include fixed costs, at least some part of the fixed costs. This means continuous investments, i.e. expanding production implies increasing investments and fixed costs, on the aggregate, while decreasing production means decreasing investments and depreciation, on the aggregate. In the base model, the technical change is mostly exogenous. Increase in production efficiency is fully exogenous, while productivity is partly exogenous: the scalar term of the production functions are given exogenous trends. Hence, the profitability of each production activity depends on the given rate of technical change.

In reality, fixed costs are sunk in the short term, but in the long term they are variable costs. In the case of depreciated but still usable buildings and machinery the farmers may continue their production in the short term even if there would be little economic surplus for the fixed production factors after the variable costs. For example, the support measures for the transitional period 1995-1999 may have encouraged some farmers to continue their production for a few more years even if there would be no intentions to continue after this. On the other hand, there are farmers who are obliged to carry on production even with low income after the variable costs.

If all fixed costs were always taken into account in the model, the model results would be always long term results which would not reflect short or medium term reactions of farmers. On the basis of the production trap implied by irreversible investments and incomplete information on future profitability of production (discussed in Chapter 5), some part of the fixed costs are always sunk costs. There are always farmers who have recently invested and they are obliged, or “trapped” to stay in production despite all production costs are not covered. On the other hand, if only a fraction of the fixed costs are taken into account in the model, such a solution may underestimate the rationality of farmers and their possibilities for other sources of income. Assuming too high a level of sunk costs implies misleading model results on the effects of policy changes on agricultural production.

Thus the level of sunk costs is crucial in the base model. The mechanisms of exogenous technical change are presented in Chapter 6.5.2. Despite the difficulty in the exact determination of sunk costs, however, the base model is useful in evaluating effects of technical change on agricultural production volumes and farmers' income under different policies. Although there is some uncertainty concerning the exact level of sunk costs over time, one can find sound arguments favouring the gradually decreasing share of sunk costs in farmers' decision-making in the base model.

It is assumed in the base model that all the fixed costs concerning buildings and machinery become gradually variable costs until 2010. This choice is motivated by the fact that a lot of agricultural investments were made in the 1980s and the production facilities constructed at that time will mostly wear off by 2010. The opportunity cost of capital, however, is neglected and is assumed to be completely sunk. According to (Pyykkönen 1996b), the capital embodied in agriculture was FIM 77 billion in 1995. If a 5% interest rate is applied, the opportunity cost of capital is FIM 3.85 billion annually. This is as much as 28% of all other directly measurable costs of agriculture, which were FIM 13.6 billion in 1999. The value of paid interests was only FIM 0.6 billion in 1999 (Hirvonen 2000, p. 139). Thus the opportunity costs of capital are relatively high in agriculture due to the large amount of capital embodied in farms.

However, all the other costs except opportunity costs of capital are assumed to become variable in the base model until 2010. This means that fixed production factors get gradually more weight in the decision-making of farmers. There are several reasons for this, like (1) obvious sunk cost behaviour in 1995-1999 (increased production in some production lines despite decreased profitability), (2) needs for investments in order to decrease production costs and because the production capacity built before 1995 is wearing off, and (3) the increased uncertainty of prices and subsidies. Let us discuss each of these issues in turn.

1. First, the agricultural investments made before 1995 were made in a very different economic environment compared that after 1995. There is still a lot of usable production facilities constructed before the EU integration. Since the profitability of agricultural production has decreased considerably since 1994 (Ala-Mantila et al. 2000, p. 60-62), farmers have not been able to get as high revenues (producer surplus) to the fixed production factors as they expected when deciding on the investments. The relatively stable or increasing production volumes of agricultural products despite the decreased profitability in 1994-1999 reflects not only the increased investments in more efficient production technology, but also the fact that many farmers continue production without investments despite the decreased profitability. Only the production of beef, which has been relatively unprofitable compared to other products since 1994, has decreased. Only a fraction of farms have invested in larger and more efficient production units while the major-

ity of farmers have continued production using their existing production facilities since 1994. Hence, one can conclude that that there has been excess production during 1995-1999 with regard to the revenues which do not cover all production costs. If this relatively high level of sunk costs is kept fixed until 2010 in evaluating the effects of agricultural policies, one may seriously underestimate the rationality of farmers and obtain misleading results. If farmers are rational profit maximisers, as assumed in this study, the share of sunk costs should decrease and the fixed costs should have an increasing weight in farmers' production decisions in the future years. Almost all farmers in Finland are professional farmers and there are relatively few hobby farmers who can accept considerable financial losses.

2. Second, investments to larger and more efficient production units are vital for farmers. Since the product prices are largely determined on the EU markets and no increase can be expected in agricultural supports, decreasing the production costs is the only way of increasing profits for most farmers. Since the inflation of the input prices is not compensated to farmers, there is a constant pressure in decreasing the production costs. Farmers who have invested in larger production units and use labour and capital relatively efficiently are able to get higher revenues than farmers who have not invested in efficient production facilities.
3. Since the future prices and supports are highly uncertain, farmers set higher requirements on the profitability of investments than they used to set before 1995 when most of the present production facilities were build. Farmers are bound to search for higher profits more actively than they used to do in the quite safe policy environment before 1995. Increased uncertainty will result in higher requirements for profitability and thus the importance of fixed costs will increase in farmers' decision-making. Farmers also gradually learn the stochastic properties of prices and make more realistic expectations of future revenues.

Investment aids can simply be incorporated into the sunk costs. This means that publicly financed investment aid increases the sunk costs, i.e. the share of fixed costs that are neglected in the decision making of farmers. Since the majority of farmers have not yet invested after 1994, only a fraction of farms have received investment subsidies. On the aggregate level, the investment aid fully influences the production volumes and farmers' income only after all investments have received the investment aid. Since it is assumed that all fixed costs due to buildings and machinery become variable until 2010 in the base model, the investment aid fully affects the production levels and income only in 2010 and after.

The level of sunk cost is different in different lines of production. The initial levels of sunk costs during 1996-1999 have been used for model calibration. For example, the expanding pork production in 1995-1998, which is mainly due to investments fuelled by transitional aids and investment aids, can be replicated by adjusting the sunk costs during the simulation years 1996-1999. After 1999 the share of fixed costs (concerning buildings and machinery) taken into account in the decision making increase linearly to the level of 100% minus the share of investment aid until 2010. Thus, the exogenously given sunk costs represent long-term investment behaviour influencing the production quantities in 1996-1999.

Using this kind of reasoning one may obtain consistent results concerning the medium and long term effects of different policy options or scenarios of technical change on agricultural production volumes and farmers' income. Assuming slightly more or less sunk cost in the analysis should not drastically change the comparative analysis of different policy options or scenarios of technical change since the same assumptions of sunk costs are used in all policy scenarios in the base model.

6.5.2. Increasing the efficiency of the production

Use of inputs, like the use of labour and capital on farms, is changing due to the decreased product prices and increased direct supports after the EU membership. Lower product prices and direct support per hectare and animal give stronger incentives for extensive production, i.e. reducing costs per hectare and animal, than the previous agricultural policy characterised by high prices and low direct supports. Less labour and capital as well as some physical inputs should be used in production if production costs were to be decreased.

More efficient use of labour and capital requires larger farm size or investments in new and more efficient production techniques. A sufficiently large farm size is needed in order to decrease both labour and capital costs per unit produced, however. Thus the increase in farm size seems to be inevitable if production costs are to be reduced. The average farm size and investments in new production facilities increased in 1996-1999. Since the majority of the existing farms have not, however, yet committed to investments after 1994, it can be expected that the efficiency in the use of both variable and fixed production inputs is still going to increase in Finnish agriculture.

It is assumed that productivity development is independent of the increase in the production efficiency, and labour and capital costs can be reduced without lowering crop and animal yields. This assumption is confirmed by the increased milk yields of dairy cows during 1994-1999, for example, even if the average size of dairy farms have increased in 1995-2000 (MTTL 2000). There is little, if any, empirical evidence that increasing the farm size and production efficiency would influence crop and animal yields in Finnish agriculture.

The most important rationale in investing to new production technology is to substitute capital for labour. Capital costs and other fixed costs per units produced can be at the acceptable level only if the farm size is large enough. The dependency between the use of inputs, production costs, and farm size has been estimated on the basis of the bookkeeping data of Finnish farms collected by the Finnish Agricultural Economics Research Institute. It has been noted that a curve of the form

$$\log C = a - b \log KK \tag{6.40}$$

is best suited for the data. C is the production cost per unit, KK is the average size of the farm, and a and b are positive parameters (Niemi et al. 1995, p. 136). In the model the use of inputs decreases according to this functional form to the target value, which can be set directly e.g. as 90% of the value of 1995. In the base model parameters a and b were not estimated, but function (6.40) is calibrated to run from the initial value to the final value as a function of time, i.e. from 1995 to 2005 or to 2010, for example (Figure A-3 in Appendix). In this case the decrease is not dependent on the growth in the average farm size, but it can be considered to have been caused, apart from this, by other measures to rationalise production. The parameters of equation (6.40) were estimated in Lehtonen et al. 1999 using cost differentials of farm models which are based on bookkeeping data (Ala-Mantila 1998). Hence, a linear increase in the average farm size (in time) is assumed in the base model. The target levels may be set on the basis of earlier development, or it can be examined what kind of increase in the efficiency a certain support policy would be required in order to maintain agricultural production at the desired level.

The decrease in the use of inputs as a function of the average farm size or time has been set for the hours of human labour and machine work as well as depreciation of the machinery and buildings, interest expenditure, and overhead costs. The specific target levels, i.e. the efficiency scenarios used in the actual analysis are presented in Chapter 9. Increase in the efficiency of production may result not only from the increasing farm size but also from other measures to rationalise production processes, such as joint investments of farmers and the introduction of new technology on a small scale.

6.6. Endogenous technology diffusion

Increasing production efficiency results from investments to new production technology as well as incremental improvements in existing production technology. Changes in agricultural policy, i.e. in prices and support, change the incentives for farmers to develop their farm and the production system. Technical change cannot be regarded independent of the policy in the long term.

Technical change proceeds through investments to new production technology and through incremental improvements of the existing technologies.

There is a need to link long-term investment decisions with the policy variables. Policy variables may have a substantial effect on the willingness of farmers to invest and to develop and maintain their production systems.

In this study a specific emphasis is given to the uncertainty and other retardation factors which prevent rapid changes in production technology. Farming is a risky business and investments are most often long-term investments. The duration of the investment cycle is typically between 5-20 years for machinery equipment and 20-50 years for buildings. For farmers it is rational to respond with more or less caution to rapidly changing economic conditions and not to take drastic investment actions without carefully taking into account different courses of action and uncertainty in agricultural policy.

The purpose of the technology diffusion submodel is to make the process of technical change endogeneous in the DREMFIA model. This means that investments to new technology and incremental improvements of the existing technology should be made dependent on general economic conditions of agriculture such as prices, support, production quotas and other policy measures and regulations imposed on farmers. Changing the profitability of different technologies as a result of economic and policy changes will result in different patterns of technical change. This is also influenced by direct payments financed by the state for new investment projects. When analysing long term policy effects on agriculture the submodel determining the farm-level investment decisions and the choice of production technology is in a key role. The model of technology diffusion and technical change presented below follows the main lines of Soete and Turner (1984).

6.6.1. The micro-economic model

Let us assume that there is a large number of farm firms producing a homogenous good. Different technologies with different production costs are used and firms can be grouped on the basis of their technology. Let the number of technologies be N. Each technology uses two groups of factors of production, variable factors, such as labour, and fixed factors, such as capital. A particular production technique labelled α, can be characterised by two parameters; the output capital ratio π_α and the labour capital ratio b_α. Thus if at a particular time the capital stock (per hectare or animal) in techniques of type α is K_α, the output (per hectare or animal) obtained when using the a technique is

$$Q_\alpha = \pi_\alpha K_\alpha \qquad (6.41)$$

and employed variable inputs (labour) in that technique is

(6.42)
$$L_\alpha = b_\alpha K_\alpha .$$

The average rate of return on capital for firms using the a technique, under the assumption of a common wage rate through the economy (which is exogenous), is

(6.43)
$$r_\alpha = \frac{Q_\alpha - wL_\alpha}{K_\alpha} = \pi_\alpha - wb_\alpha .$$

Total output and employment are given by summing equations (6.41) and (6.42) over all techniques α (and all hectares and animals since K_α is capital per hectare). The total capital stock is

(6.44)
$$K = \sum_\alpha K_\alpha .$$

If α represents the techniques employed in the *whole* economy then the rate of return on capital for the whole economy is

(6.45)
$$r = \frac{\sum_\alpha (Q_\alpha - wL_\alpha)}{K}$$

or using equations (6.42) and (6.43)

(6.46)
$$r = \sum_\alpha r_\alpha \frac{K_\alpha}{K} = \sum (\pi_\alpha - wb_\alpha) \frac{K_\alpha}{K} .$$

Thus *r* is the weighted average of the rate of return for each individual technique of the whole economy. Equations (6.43) and (6.45) give the rates of return for each individual technique and for the economy as a whole, respectively. Technology diffusion means that capital shifts gradually to the best performing techniques.

6.6.2. Modelling endogenous investment decisions

In specifying the investment function assumptions have to be made on how entrepreneurs (farmers) distribute their investable resources. The first assumption is that they will search for the most profitable technique to invest in.

Second, it will be assumed that not all entrepreneurs will be successful in that search. The reasons for this relate to the uncertainty about the merits and reliability of a new technique, cost and time involved in learning about it and how to use it, etc. In addition to these uncertainties, there is a considerable uncertainty about agricultural policy. Prices, subsidies and some environmental regulations, for example, may change in such a way that the optimal investment decisions today will be suboptimal in the future. Firms may rationally decide to delay the adoption of a new technique until they have more information about the experiences of other firms and future agricultural policy.

There are various ways in which such a behaviour can be modelled. Nelson and Winter (1982, p. 210-212) present some stochastic models where transition probabilities are given for the attempts to change from the current technique to the alternative, more profitable techniques. The analytical approach given below follows the main lines of Soete and Turner (1984).

Assume that at any time t a fraction of the surplus from each technique is available for investment, i.e. the amount available for investment from technique α is

$$\sigma(Q_\alpha - wL_\alpha) = \sigma(\pi_\alpha - wb_\alpha)Q_\alpha = \sigma r_\alpha K_\alpha \tag{6.47}$$

where $\sigma < 1$, the savings ratio (if farmers use outside sources for investments, such as income from forestry, σ may be greater than one as well), is assumed to be the same for all techniques. This investable surplus is divided between all firms using the α technique. Let $f_{\beta\alpha}$ be the fraction of investable surplus transferred from α technique to β technique. This transfer will take place only if the rate of return for β technique is greater than the rate of return for α technique, i.e. $r_\beta > r_\alpha$. The total investable surplus leaving α technique for all other more profitable techniques is

$$\sum_{\beta : r_\beta > r_\alpha} f_{\beta\alpha} \sigma r_\alpha K_\alpha \tag{6.48}$$

where

$$\sum_{\beta : r_\beta > r_\alpha} f_{\beta\alpha} \leq 1 . \tag{6.49}$$

The summation over β is taken only over those values of β for which $r_\beta > r_\alpha$. Therefore the investable surplus which is generated by α technique and reinvested in that technique is

$$\sigma r_\alpha K_\alpha - \sum_{\beta : r_\beta > r_\alpha} f_{\beta\alpha} \sigma r_\alpha K_\alpha . \tag{6.50}$$

On the other hand, some firms using techniques which have a lower rate of return than the α technique may transfer their investable surplus to α technique. The total investable surplus coming into a technique from the investable surplus of other techniques is

$$\sum_{\beta:r_\beta<r_\alpha} f_{\alpha\beta}\sigma r_\alpha K_\alpha \tag{6.51}$$

where the summation in this case is restricted to those values of β for which $r_\beta<r_\alpha$. Adding (6.48) and (6.49) gives the total investment in α technique

$$I_\alpha=\sigma r_\alpha K_\alpha-\sum_{\beta:r_\beta>r_\alpha} f_{\beta\alpha}\sigma r_\alpha K_\alpha+\sum_{\beta:r_\beta<r_\alpha} f_{\beta\alpha}\sigma r_\alpha K_\alpha. \tag{6.52}$$

To make the model soluble a form of the $f_{\beta\alpha}$ has to be specified. Two crucial aspects about diffusion and adoption behaviour will be included: first, the importance of the profitability of the new technique, and second, the risk and uncertainty involved in adopting a new technique. The information about and likelihood of adoption of a new technique will grow as its use becomes more widespread with a consequent growth in cumulated knowledge and experience of farmers.

To cover the first point, $f_{\beta\alpha}$ is made proportional to the fractional rate of profit increase in moving from technique α to technique β, i.e. $f_{\beta\alpha}$ is proportional to $(r_\beta-r_\alpha)/r_\alpha$. The second point is modelled by letting $f_{\beta\alpha}$ be proportional to the ratio of the capital stock in β technique to the total capital stock (in a certain agricultural production line), i.e. K_β/K. If β is a new innovation then K_β/K is likely to be small and hence $f_{\beta\alpha}$ is small. Consequently, the fraction of investable surplus transferred from α to β will be small. Combining these two assumptions $f_{\beta\alpha}$ can be written as

$$f_{\beta\alpha}=\eta'\frac{K_\beta}{K}\frac{(r_\beta-r_\alpha)}{r_\alpha} \tag{6.53}$$

where η' is a constant. Substituting (6.53) in (6.52) gives

$$I_\alpha=\sigma r_\alpha K_\alpha-\eta\sum_{\beta:r_\beta>r_\alpha}\frac{K_\beta}{K}(r_\beta-r_\alpha)K_\alpha+\eta\sum_{\beta:r_\beta<r_\alpha}\frac{K_\beta}{K}(r_\beta-r_\alpha)K_\alpha \tag{6.54}$$

where $\eta=\sigma\eta'$.

Examination of the second and third terms on the right-hand side shows that the summands are identical but for the second term β runs over all values such that $r_\beta > r_\alpha$. They can thus be combined into one sum in which β takes all possible values. Hence

$$I_\alpha = \sigma r_\alpha K_\alpha - \eta \sum_\beta \frac{K_\beta}{K}(r_\alpha - r_\beta)K_\alpha \tag{6.55}$$

or

$$I_\alpha = \sigma r_\alpha K_\alpha - \eta r_\alpha K_\alpha \sum_\beta \frac{K_\beta}{K} - \eta \sum_\beta \frac{K_\beta}{K} r_\beta \tag{6.56}$$

which, using (6.44) and (6.46), further simplifies to

$$I_\alpha = \sigma r_\alpha K_\alpha + \eta(r_\alpha - r)K_\alpha = \sigma(Q_\alpha - wL_\alpha) + \eta(r_\alpha - r)K_\alpha. \tag{6.57}$$

The interpretation of this investment function is as follows. If η were zero then (6.57) would show that the investment in α technique would come entirely from the investable surplus generated by α technique. For $\eta \neq 0$ the investment in the α technique will be greater or less than the first term, depending upon whether the rate of return for the α technique is greater than the average rate of return of all techniques (r). This seems reasonable. If a technique is highly profitable then it will tend to attract investment and, conversely, if it is not very profitable investment will decline. To summarise, the investment function (6.57) is an attempt to model the behaviour of farmers (or any entrepreneurs) whose motivation to invest is greater profitability but who will not adopt the most profitable technique immediately, because of uncertainty and various other retardation factors.

Summing equation (6.55) over all α the total investment for the whole economy (or only for agriculture in a partial equilibrium setting),

$$\begin{aligned} I = \sum_\alpha I_\alpha = \sum_\alpha \sigma r_\alpha K_\alpha + \sum_\alpha \eta(r_\alpha - r)K_\alpha = \sum_\alpha \sigma r_\alpha \frac{K_\alpha}{K} K + \\ \sum_\alpha \eta r_\alpha \frac{K_\alpha}{K} K - \sum_\alpha \eta r \frac{K_\alpha}{K} K \end{aligned} \tag{6.58}$$

or, using (6.43) and (6.45),

$$I = \sigma r K = \sigma(Q - wL). \tag{6.59}$$

Total investment is given by the classical investment function: all investable surplus (which depends on the savings ratio σ) goes into investment. The important point about (6.56) is that this total investment is distributed among the different techniques according to their profitability and accessibility. The most profitable technique is not equally accessible for all farmers (or any entrepreneurs) and thus farmers also invest in other techniques which are more profitable than the current technique. When some new and profitable technique β becomes widespread and K_β/K increases, more information is available about the technique and its characteristics. Thus, the new technique becomes more accessible and farmers invest in that technique at an increasing rate. This rate also depends on the difference in profitability between the new and existing technologies.

Assuming depreciations and using the investment function (6.57) the rate of change in capital invested in α technique is

$$\text{(6.60)} \qquad \frac{dK_\alpha}{dt} = [\sigma r_\alpha + \eta(r_\alpha - r) - \delta_\alpha]K_\alpha$$

where δ_α is the depreciation rate of α technique. Thus the growth rate of α technique is directly proportional to the rate of return of the α technique as well as to the difference between α technique and the average rate of return of all techniques and to the depreciation rate.

The technology diffusion model presented incorporates quite a simple technology diffusion process. Because the analysis is made at the level of techniques rather than firms, it does not allow one to introduce into the analysis the various behavioural assumptions about both the innovating and imitating firms, such as the effect of firm size and market structure on diffusion and adoption.

Given the very limited resources of this modelling exercise, it is preferable to model the technical change at the level of individual technologies and not on the level of different kinds of firms. The technology diffusion model works consistently on the aggregate level and can be easily applied in the DREMFIA model where representative farms with a single production technology is assumed. The input use of the representative farms in the DREMFIA model can be calculated as a weighted average of the different technologies of the diffusion model. The technology diffusion model is a separate sub-model which calculates technical change and new input coefficients separately through algebraic equations without increasing the complexity and computational burden of the optimisation block of the DREMFIA model. Thus, the technology diffusion model describes the aggregate level technical change while the optimisation model describes the dynamic dis-equilibrium process, i.e. the annual market reactions to the changes in prices, subsidies and technology.

6.6.3. Aggregate level technical change and sunk cost behaviour

The input use of the representative farms in the DREMFIA model is calculated as an weighted average of the different technologies. An aggregate input-output coefficient of fixed inputs (like depreciations per hectare or animal) in certain production line can be written as

$$Z = \frac{1}{K}\sum k_\alpha Z_\alpha K_\alpha \tag{6.61}$$

where Z_α is the input-output coefficient (per hectare or animal) of α technique and k_α is calculated as

$$k_\alpha = 1 \quad \text{if} \quad \frac{dK_\alpha}{dt} = [\sigma r_\alpha + \eta(r_\alpha - r) - \delta_\alpha]K_\alpha \geq 0 \tag{6.62a}$$

$$k_\alpha = -\frac{\sigma r_\alpha + \eta(r_\alpha - r) - \delta_\alpha}{\delta_\alpha} \quad \text{if} \quad \frac{dK_\alpha}{dt} = [\sigma r_\alpha + \eta(r_\alpha - r) - \delta_\alpha]K_\alpha < 0 \tag{6.62b}$$

where δ_α is the depreciation rate of α technique. This means that contracting technologies, i.e. techniques for which dK_α/dt is negative, require less capital inputs than those techniques for which dK_α/dt is non-negative. This means that replacement investments to α technique may be less than depreciations. This implies decreasing capital stock K_α. If there are no investments in α technique, the capital stock K_α decreases by the depreciation rate and no fixed costs are required in production in the year concerned i.e. fixed costs are not taken into account in the annual optimisation. This represent sunk cost behaviour; if a certain technology is making loss after fixed costs or if it is less profitable relative to the other techniques, it is sensible not to invest in that technique. Such techniques, however, may be used as long as they can earn any investable surplus. Since the capital stock of relatively less profitable techniques is decreasing at the given depreciation rate, the less profitable techniques may still be wider spread than the new superior techniques for some time.

This kind of sunk cost behaviour seems to be quite typical for Finnish agriculture. Many farmers do not want to invest in a new and more profitable technique before the capital stock invested in the existing technique is depreciated (this kind of production trap was discussed in Chapter 5). This makes agricultural production quite insensitive to price and policy changes in the short term, while the rate of change accelerates in the long term. This is also due to the diffusion of new technology as well as information and experience of other farmers who are ready to invest in new production techniques in the very first years after a policy change.

6.6.4. Endogenous flexibility constraints

Flexibility constraints are introduced in the DREMFIA model to ensure that changes in the number of hectares and animals as well in endogenous feeding coefficients will be realistic (not too large in the short term). The upper bounds for the animal production activities are made endogenous in the extended model with technology diffusion model simply by calculating the number of available animal places (in livestock buildings). The number of available animal places can be calculated by dividing the capital embodied in each technique by the price of each animal place. *Summing up the number of animal places of all techniques provides the number of animal places available, which serves as an upper bound for the animal production activities.*

At the farm level the lower bound of each animal production activity can be zero. If prices and subsidies do not cover the variable costs it is optimal not to produce at all. At the sector level, however, zero production levels or significant drops in aggregate production are very unlikely. Prices of meat would collapse if all dairy farmers, for example, would sell their animals to the slaughterhouses. As discussed in Chapter 5, the level of sunk costs depends on the difference between the initial investment costs and the resale value of the investment. If the resale value of dairy cows, for example, goes down, fewer farms are willing to exit production even if production is unprofitable. Irreversibility of the investments and uncertainty of future prices imply an option value for waiting for more information on future prices and support. Thus farmers react to low prices and support with caution and economic theory supports the imposition of some lower bounds for aggregate animal production activities. Consequently, lower bounds for the number of animals are used in the extended model.

Model of technology diffusion can also be implemented in the case of crop production. One may include different production techniques with different costs for every crop. This, however, requires an extensive data work since the relative differences in costs of different techniques are different for different crops. For this reason the technology diffusion is not implemented for crop production in the current version of the model. Annual changes in crop areas are constrained by the upper and lower bounds.

The feeding variables, i.e. the amount of each feedstuff given to each type of animal, need to be constrained by the flexibility constraints as well, since the feed diets may change rather flexibly and independently of the technical properties of the feeding equipment.

6.7. Indicators of environmental quality

Certain environmental indicators are calculated for each production region in the model using the values of the production variables. One such indicator is regional aggregate nutrient balance, i.e. the difference (positive or negative, or zero) between incoming and outgoing nutrients per hectare per year. The nutrient balance shows the potential nutrient run-off from the fields. One needs data concerning the nutrient content of different crops, fertilisers, nutrient content of manure of different animals, as well as fertiliser use and crop yield levels of different crops in order to calculate the nutrient balance. Since nutrient balances are typically very different on animals farms and other types of farms with no livestock, the nutrient balance is calculated separately for the area under feed crops and for the area under the other crops. Since the arable land is not separated between animal and other farms in the model, it is assumed that manure is spread only over the area under fodder crops.

The DREMFIA-model calculates the nutrient balance for both nitrogen and phosphor. Gross and net nitrogen balances are calculated separately since some fraction of nitrogen contained in animal manure will run off in the form of gas emissions. Changes in the nutrient balance may result from changed use of fertilisers, changed crop yields, or changed allocation of land under different crops. On the basis of the evolution of the nutrient balances in different regions one can make conclusions of the potential effects of different agricultural policies on the nutrient run-offs.

In addition to nutrient balance, the DREMFIA-model also calculates average nutrient and manure input per hectare and average nutrient output per hectare in different regions. Ammonia emissions in the whole country are calculated, given some coefficients concerning ammonia emissions per animal. The ammonia emission indicator produced by the DREMFIA model is used when evaluating future greenhouse emissions from Finnish agriculture. The crop area under pesticide application is also computed. A large set of indicators are used in evaluating the environmental and economic sustainability of agriculture.

6.8. Technical set up

The technical implementation of the DREMFIA model consists of five main parts: (1) The main program with the loop structure and dynamic specifications, (2) the optimisation block, (3) input (data and policy scenario) files, (4) the programs which calculate agricultural income and environmental indicators on the basis of the model results, and (5) write the results to spreadsheet files. In total, there are 8 input files and 13 standard output files, and 5 additional spreadsheet files for environmental indicators.

The optimisation block of the DREMFIA model consists of 59 equations blocks with 1,207 single equations. There are 2,819 variables in the optimisation block which is solved consecutively from 1995 to 2010. The number of non-zero elements in the optimisation block is between 13,758-13,795, depending on the solution year. The number of non-linear non-zeroes, i.e. the non-zero elements connected to non-linear variables, is between 4,432-4,474. The DREMFIA model is thus fairly large. For example, the model of Apland and Jonasson (1992, p. 27) consisting of many products and regions included 220 equations, 718 variables and 4,484 non-zeroes, of which 46 were non-linear. Thus the optimisation block in the DREMFIA model has relatively more non-linearities than standard optimisation models maximising producer and consumer surplus with few non-linearities. Non-linearities are desirable because the linearity results in abrupt and unrealistic changes in supply in response to exogenous changes, which is usually considered a weakness in agricultural sector models.

The major source of non-linearity in the DREMFIA model are the endogenous feeding coefficient as well as the demand function specification with imperfect substitutability between domestic products and imports. There are also non-linear milk yield functions for dairy cows. The non-linearities in the objective, and the non-linearity in the constraints, in particular, make the model quite difficult to solve.

A non-linear optimisation problem can be coded and solved using many different softwares. Since the DREMFIA model is a very large recursive programming model, it is better to use a high level programming language which makes it possible to write the equations concisely in the form which can be easily understood also by those who have little programming experience. Matrix generators make it possible to write a quite simple and “compressed” code where only one statement per each category of an equation type or a product class is needed. Matrix generators make it easier to avoid programming errors, since products, inputs, and regions, for example, can be defined as sets. The equations are automatically generated over all inputs, products or regions contained in the sets. When adding or deleting some products or inputs one needs only to add or delete items in the appropriate sets. This makes it possible to write a code that is easy to change and understand. One may also include data or parameter values into the code directly using the product or input labels in tables or vectors.

Non-linear objectives and constraints, in particular, make the model solution of the DREMFIA-model quite tedious in mathematical and algorithmic terms. A solution for such a large optimisation problem may not be found using any software. For example, the solvers available in some spreadheets are not designed to solve large-scale non-linear problems. The process of the optimisation algorithm and possible error conditions cannot be traced very well in spreadsheets. It is usually not possible to change the options and parameters in the optimisation algorithm in order to make the solution process faster or more reliable.

Hence, it is desirable to use matrix generator based software and programming languages specifically tailored for the solution of large scale non-linear optimisation problems. Such software usually have a variety of different options which affect the performance of the algorithm. Such options can be used to fit the algorithm better the particular problem at hand. One may, for example, adjust the step length of gradient-based optimisation algorithms, or the frequency of evaluation of non-linear constraints which influence the speed and reliability of the solution process. Some default values of the options fit most problems relatively well, but in some special cases one may be able to improve the solution process considerably by adjusting some key options. Arbitrary adjustment of solver options, however, is to be avoided. There is a risk of making things worse than better when arbitrarily adjusting the solver options. The documentation of some solvers, however, gives a detailed description on the algorithmic details and the meaning of the solver options. During the computation some solvers provide a lot of useful information on the characteristics of the problem and the optimisation process, like the number of linear and non-linear equations and variables, and error conditions and possible sources of errors.

DREMFIA-model has been implemented using GAMS (General Algebraic Modeling System, version 2.25) (Brooke et al. 1992). GAMS is suited for a variety of computing platforms. Spreadsheet data can be read into GAMS model and some data can be exported to spreadsheets. There are no graphical features in the GAMS system itself but some additional modules are available for plotting the model results, also during the solving process. The graphs and plots can be generated and the results can be further manipulated in specific graphical softwares or on spreadsheets. The results of the solve procedure are put into separate files that can be used as input to other GAMS models.

Different alternative solution algorithms tailored for GAMS can be used. For non-linear programming problems there are two basic choices: MINOS and CONOPT solvers. DREMFIA-model is constructed using a MINOS-solver. Solver options of MINOS are adjusted to fit the solver to this particular problem. MINOS-solver uses reduced gradient method combined with quasi-Newton-method in the solve procedure. MINOS calculates reduced gradients analytically using symbolic differentiation. A so-called projected Lagrangian algorithm is used in handling non-linear constraints. In the case of non-linear constraints the convergence to a unique solution cannot be found in all cases, but the user has a possibility to influence the solution process by changing some solver options (Brooke et al. 1992, p. 203-205). In the DREMFIA-model most non-linearities appear in the objective, while there are some, but relatively few, non-linearities in the constraints because of endogenous feeding variables. Most constraints are linear. However, at the default options of MINOS it takes more than 15 minutes (while using 550 MHz Pentium III processor and 64 Mb memory available) to solve the full DREMFIA model for years 1995-2010.

Adjusting some solver options of the MINOS solver decreases the solution time close to 50%. Since the non-linear constraints including a large number of feeding variables are heavy to update, setting "Minor iterations 80" (default 40), increases the number of iterations between the constraint updates and thus makes the solution considerably faster. This means that the non-linear constraints are not evaluated as often as stated in the default settings. This is also a safe solution, since the functional forms of the objective and the constraints are quite smooth, and exactly the same solution can be computed using the standard default settings of the solver options. The solution time of the model was also reduced by setting "Start assigned nonlinears nonbasic". This means that the non-linear variables are not the first variables to enter the basis in the solution algorithm, which makes it easier and faster for the solver to find the optimum. Adjusting other solver options did not make the solution process any faster. It was important, however, that the Lagrangeans of the non-linear constraints are updated as often as the objective function (which is the default in MINOS). Otherwise MINOS will not always find an optimum. Using the solver options described above the MINOS solver has always been successful in finding a unique optimum, even if rather different initial values are given for the variables. It has turned out that in all applications the results can be reproduced exactly.

The dynamic specification, i.e. recursive solution of many consecutive optimisation models, of the DREMFIA model is implemented by solving the optimisation problem in loop through years 1995-2010 using basic features of GAMS. The outcome of each solve is used as an initial value for the next solve. Exogenous trends for consumption, prices of primary inputs, productivity, as well as for the production efficiency in the base model, are specified in the loop between the solve procedures.

Data are incorporated from several spreadsheet files into the model. Different policy scenarios are defined in GAMS files which are selected through the "$include" statement into the model. Model output is written to spreadsheet files by a specific GAMS program. There are separate GAMS programs which calculate agricultural income and a set of environmental indicators, and write them into spreadsheet files.

The model as a whole is a large information processing system providing a large set of information for different research areas of agricultural and environmental economics. One should note, however, that the model can answer only a limited subset of research questions, namely those connected with aggregate level impacts of economic and policy changes. Thus the model is to be used as a complementary part of some research projects, not as a primary tool of all research projects. The principle of "one problem per model" holds, even if the DREMFIA model may serve as a research tool of many projects where the aggregate level impacts are important.

6.9. A moving equilibrium formulation

Flexibility constraints given to the decision variables, such as hectares of crops, numbers of animals, and feeding variables, can be relaxed by changing one option in the source code. When selecting this option the hectares of crops and the numbers of animals, as well as the feeding variables, may change up to 50% annually. In the case of the feeding variables, number of animals and the areas of most crops, such large annual changes are by no means realistic because of biological and technical constraints. In the case of wheat and rye, however, in time series data of crop areas one can find annual variations even larger than 50% which are explained by weather conditions in sowing period (MTTL 2000, p. 30).

The relaxed model, i.e. the model where the flexibility constraints are widened so that the annual changes may be as large as 50%, can be used in assessing the theoretical equilibrium position of the agricultural sector at given prices and subsidies. The relaxed model also assumes that all fixed costs are fully variable, and all production inputs are immediately adjusted. While the relaxed model is solved for each year starting from 1995, the relaxed model is a kind of “moving equilibrium model” which represents immediate equilibrium movements as the prices and subsidies change. The use of such a model, however, is rather limited, since equilibria seem to be rare in Finnish agriculture. Agricultural economists and policy-makers are more interested in dated results which describe the adjustment of Finnish agriculture to changed conditions rather than analysing equilibrium properties of the existing production allocation which most obviously does not represent an economic equilibrium.

7. Data and parameter estimates

7.1 Statistical and other sources of data

Data obtained from official statistics, i.e. statistics produced by statistical authorities in Finland, have been used extensively in this study. The number of animals and hectares of each crop in different regions are obtained from the official statistics and used as initial values of the production variables. Regional crop yield levels, consumption of different food items, as well as prices of inputs and outputs were also obtained from the official statistics. Initial volumes of exports and imports can be obtained from foreign trade statistics. A number of statistical data sources are published by the Information Centre of the Ministry of Agriculture and Forestry. A lot of data are publicly available through the Internet (http://www.mmm.fi/tike/english/agristatistics.htm). Statistics Finland also publishes some agricultural data. In this study, Business and Income Statistics of Farming (Statistics Finland 1995) were used in estimating the level of fixed costs in each production line in agriculture.

In addition to the official statistics produced by statistical authorities, some other sources of data have been used in this study. In particular, data of the application of production inputs, collected by the Rural Advisory Centres, are used. Detailed farm level data of more than 1,000 farms can be obtained from the FADN (Farm Accountancy Data Network) system managed by the Agricultural Economics Research Institute of Finland. Initial values for feeding variables have been obtained from recording results of the Rural Advisory Centres (MKL 1997). Such data are compiled from large samples of farms. The dairy recording system, for example, covers close to 70% of dairy cows in Finland. Feeding requirements and recommendations, as well as fodder unit coefficients and coefficients describing protein and roughage content of different feedstuffs, are also published by the Rural Advisory Centres (MKL 1996a).

The Rural Advisory Centres provides detailed farm-level production cost calculations on different types of farms in each production line (MKL 1995). Such information is primarily intended for farmers who can use the calculations in estimating their production costs, but can also be used when specifying the exact specifications of different inputs needed in production. Similar information is also produced by the Agricultural economics Research Institute of Finland. The farm-level production cost calculations on different farm types are calculated by Ala-Mantila (1998) and Riepponen (1998) using FADN data. Agricultural total calculations (Hirvonen 2000) have been used in validating the production costs and the total use of each type of production inputs.

7.2. Production costs and the use of production inputs

7.2.1. Validating the aggregate use of inputs

Even if some of the data sets mentioned above are based on large samples of farms they cannot, however, be used directly as regional aggregates of the use of inputs. The use of inputs calculated on the basis of sample results need to be slightly adjusted in order to match the value of inputs presented in total calculations of agriculture.

Total agricultural calculations are based on the actual annual cash flows in agriculture. This leaves some uncertainty in the estimated total value of inputs used in one year since all inputs purchased need not be used in the same year. Nevertheless, by comparing the value of inputs in the time series of total calculations (Hirvonen 2000, p. 139) one can see that there are relatively small annual fluctuations in the value of individual inputs, and thus one can use the value of different inputs presented in total calculations in validating the input use levels of individual farm-level production cost calculations (like MKL 1995).

The production cost calculations of the Rural Advisory Centres are well compatible with those of the FADN data, calculated by Ala-Mantila (1998). This is understandable since both production cost calculations are based on empirical information of the actual use of inputs on farms. There are considerable differences, however, in the use of inputs between farms of the same size (Riepponen 1998). This leaves some uncertainty concerning the average use of inputs and average production costs. On the basis of sample data one does not know the level of average production costs exactly. Hence, minor adjustments can be made in the use of inputs in order to match the value of inputs presented in the agricultural total calculations. The total value of each input in the DREMFIA model should match quite closely the value of each input presented in the total calculations of agriculture. This is why slight adjustments have been made in the use of production inputs, derived from sample data.. The resulting input use specifications are still quite close to those implied by the sample data.

Table 7.1 illustrates the level of detail of the input and production cost specification in the DREMFIA model, as well as the slight modifications made in the use of inputs in order to match the total value of each input to those in the agricultural total calculations. Hired labour is included in the model as an input in most production activities since there are some costs due to hired labour in the agricultural total calculations. This makes the total labour input as well as the total production costs per hectare slightly higher in the model than in the calculation presented in MKL (1996).

In the case of fixed inputs, i.e. capital costs per hectare or animal, however, it is more difficult to divide the total capital costs between different production

Table 7.1. Use of production inputs per hectare in barley cultivation in Ostrobothnia in 1995.

Input	Use of inputs in the production cost calculations of Rural Advisory Centres (kilos, hours, units)	Use of inputs in the model (kilos, hours, units)	Price of inputs (FIM per unit)	Value of input per hectare (FIM)
Labour	17	18	50	900
Fertiliser	333	350	1.3	455
Seeds	190	190	1.39	264.1
Pesticides	1	1	100	100
Tractor hours	11.5	10	17	170
Tractor depreciation	-	10	23	230
Harvesting hours	1.4	1.4	69	96.6
Depreciation of harvesting machines	-	1.1	500	550
Variable grain drying costs	3500	3400	0.05	170
Fixed grain drying costs	-	2	200	400
Depreciations of other buildings	-	1	175	175
Depreciation of bridges and ditches	-	3	40	120
Other depreciations	-	9	16	144
Overhead	-	1.45	250	290
Interests	-	1.45	140	203
Rents	-	1.45	130	188.5
Salaries (hours)	-	2	50	100
Total variable costs	2144.1			2255.7
Total fixed costs	-			2300.5
Total costs	-			4556.2

Source: DREMFIA model, MKL 1996a, p. 143.

lines than in the case of variable inputs. The use of fixed inputs have not been recorded as carefully as the use of variable inputs, like feed-stuffs, since the use of fixed inputs are more difficult to measure. For this reason, Business and Income Statistics of Farming (Statistics Finland 1995), which presents the taxable income and expenditures, and assets and liabilities, per agricultural holding by production sector, was used in order to allocate the fixed costs of agriculture on different production lines. The aggregate level of fixed costs in the Business and Income Statistics of Farming, which is based on taxation data, were lower than the fixed costs in the agricultural total calculations. For this reason, the fixed costs to be shared by the different production lines were taken from agricultural total calculations (Hirvonen 2000). The shares of each production line of the total fixed costs were calculated directly using Business and Income Statistics of Farming (Statistics Finland 1995, 48-49).

Using the Business and Income Statistics of Farming (Statistics Finland 1995) it was also possible to separate the fixed costs of crop production from the costs of animal production. In the DREMFIA model crop production is a separate activity from the animal production activities (even though connected by the balance constraints of feedstuffs), whereas the farm-level data, and all the statistical sources based on farm-level data, describe the total value of all fixed inputs on each type of farms. Hence, it is necessary to separate the fixed costs of crop production from the fixed costs of animal production. This was done as follows. First, the fixed costs (in each fixed cost category) of crop farms (with no animals) per hectare were calculated. This figure represents the fixed costs per hectare needed in crop (mainly grain) production. When this figure is multiplied by the average area of each type of animal farm, one obtains the fixed costs of crop production on different types of animal farms. When this fixed cost of crop production is subtracted from the total fixed costs of animal farms, one obtains the fixed costs of animal production activities. As presented in Table 7.2, 42% of the total fixed costs of Finnish agriculture can be assigned to crop production activities and 58% to animal production activities.

Table 7.2. The distribution of depreciations (FIM million and %) on crop production (CROP) and animal (ANI) production, as well as within different animal production lines.

		Dairy	Beef	Pork	Poultry	Total of animal production	Crop production	Total
Buildings	ANI	65%	61%	41%	55%	60%	0%	38.8%
	CROP	35%	39%	59%	45%	40%	100%	61.2%
	Total	470	74.6	119.4	34.3	698.3	380.2	1078.5
Machinery	ANI	41%	32%	41%	55%	41%	0%	22.5%
	CROP	59%	68%	59%	45%	59%	100%	77.4%
	Total	995.5	154.1	240.8	77.1	1467.4	1189.3	2656.7
Bridges	ANI	21%	5%	19%	24%	19%	0%	10%
	CROP	79%	95%	81%	76%	81%	100%	90%
	Total	87.3	12.1	19.7	5.4	124.6	117.2	241.8
Total		67.8%	10.5%	16.6%	5.1%	57.6%	42.4%	100%
		1552.8	240.8	379.9	116.8	2290.3	1686.7	3977

Calculated using Business and Income Statistics of Farming (Statistics Finland 1995, p. 48-49).

The calculations presented in Table 7.2 describe the distribution of fixed costs between animal and crop production activities in 1994, which represents the initial situation before the EU membership and a starting point in the model simulation. The fixed costs of animal production activities are assigned to different types of animal farms. One may calculate that 67.8% of the total fixed costs in animal production can be assigned to dairy farms, 10.5% to beef farms, 16.6% to pig farms, and 5.1% to poultry farms.

7.2.2. Regional differences in the use of inputs

There are no representative statistics available on the use of all inputs and production costs in each production line in different regions. Aggregate regional data on production costs of all farms in all regions are available in the Business and Income Statistics of Farming (Statistics Finland 1995). However, one needs not only regional aggregate production cost data, or aggregate production cost data of each production line in the whole country, but regional production cost data of each production line. Such data are hard to get.

Only the data concerning the milk yield of dairy cows and the feed use of cattle animals, collected by the Rural Advisory Centres, can be considered reliable and somewhat representative at regional level. However, even this data need to be slightly adjusted in order to get average milk yield and feed use data because the milk yield per dairy cow is higher on the farms included in these records than the average milk yield per dairy cow in Finland. Nevertheless, the structure of the animal diets can be considered representative, at least approximately, since there were 12,000 farms in the sample in 1995-1996. This is 40% of dairy farms in Finland in that period. Even if the average feed use of dairy cows is lower than that in the sample, the composition of animal diets, i.e. the relative shares of the feedstuffs, in the sample is likely to be close to the actual average composition.

Differences in production costs, i.e. in the use of all production inputs, between regions have been analysed by Riepponen (1998) and Rantala (1997) based on sample data which cannot be considered representative. Riepponen (1998) compared the production costs of milk, grain and pork using FADN data from the year 1995. Unfortunately, there were only 376 farms in the sample and the number of farms in the sample was very low in some areas. Hence, the average production costs cannot be seen representative in all regions. The farms in the FADN sample are quite typical family farms but slightly larger than the average farms in Finland. Most of the dairy farms in the FADN sample are located in the northern support areas C. Only 70 milk producing farms were located in Southern Finland (support area A and B). The results of Riepponen (1998) show that there are only slight, if any, differences in the production costs of milk in support areas A, B, C1, C2 and C2P. The production costs per a litre of milk are somewhat higher in the most northern support areas C3 and C4 than in the other parts of the country.

Rantala (1997) calculated the production costs of milk in 1996 using a sample of 381 farms which are about the same size as the farms in the FADN sample used by Riepponen (1998), even if the samples are different. All regions do not have an equal weight in the sample, however. For example, in Central Finland only the western part was adequately represented, and the production conditions are somewhat different in the eastern parts which is an equally important region in milk production as the western part. Furthermore, there were only 10 farms from support area A in the sample of Rantala. According to the results, the production costs are considerably lower in the southern parts of the country (support areas A and B) than in the north (support areas C3 and C4). This is in contrast to the results of Riepponen (1998) which showed little, if any, difference in production costs in Southern Finland (areas A and B) and Central Finland (support areas C). One should note, however, that the results are not fully comparable, since they are calculated using different samples, data from different years, and slightly different assumptions in the calculation. Annual weather conditions, which may be very different in different regions in the same year, affect the feed and production costs. The production costs calculated by Riepponen (1998) and Rantala (1997) are presented in Tables 7.3 and 7.4.

One may conclude that time series data of a fixed representative farm sample would be needed in estimating the differences of production costs in different regions. Such data is hard to get, however, and no such analysis has been made in Finland.

Table 7.3. Production costs of milk (FIM/litre) according to the sample results of Riepponen (1998).

Support region	A	B	C1	C2	C2P	C3	C4
Number of farms	14	56	69	132	39	57	9
Average size of farms	19	19	19	17	16	16	14
Production cost /litre	3.54	3.38	3.40	3.56	3.61	3.85	3.78

Table 7.4. Production costs of milk (FIM/litre) according to the sample results of Rantala (1997).

Support region	A	B	C1	C2/C2P	C3	C4
Number of farms	10	102	54	176	31	3
Average size of farms	21.3	17.1	19.1	16.6	16.3	11.3
Production cost /litre	2.45	2.89	2.97	3.11	3.13	3.82

Including the regional variations in the production costs in the sector model is possible, however. Differences in the production costs between regions are already partly included through the regional yield levels. Differences in the prices of feedstuffs as well as the differences in animal diets between the regions also result in different production costs. For example, the industrially processed feedstuffs are more expensive in Northern Finland than in Southern and Western Finland (also noted by Rantala (1997) based on the data from 12,000 farms). The industrially processed feed-stuffs are used more in the northern and eastern parts of Finland than in the western and southern parts of the country. This is understandable, since the crop yield levels are higher in the southern and northern parts of Finland than in the northern and eastern Finland. There is also more land available in southern and western parts of Finland compared to eastern and northern Finland where the parcels are relatively small and often separated by long distances. The crop yields and the availability of land influence the amount of purchased feedstuffs. Yield levels, animal diets and the prices of feedstuffs are already included into the model.

What are not included in the basic data of the model, however, are the differences in the use of labour and fixed costs per hectare and per animal in different regions. There is little, if any, representative data on the use of labour and capital on farms in different regions.

Structural statistics can be used in approximating the differences in the use of capital and labour per hectare and per animal between the regions. In this study it was assumed that the use of labour and capital per hectare and animal is proportional to the farm size. The relative differences in the farm size, however, may not exactly equal to the relative differences in labour and capital use per hectare and animal. This is because of the fact that farms are using quite similar production techniques in all parts of the country, and slight differences in the farm size do not result in very different production methods or techniques. For this reason only relatively small differences were assumed in labour and capital costs in different regions. In crop production the production costs per hectare are slightly higher in Northern and Eastern Finland than in the southern and western parts of the country. The use of labour and capital in Northern Finland is assumed to be roughly 10% higher per hectare compared to the use of labour and capital in the Southern Finland. In the production of silage, however, the production costs per hectare in Northern Finland are lower than in other regions due to the fact that only 1-2 crops of grass silage can be harvested annually in the north and 2-3 crops could be harvested in other regions (Table 7.5). The crop production costs per kilo produced, however, are considerably higher in Northern and Eastern Finland than in Southern and Western Finland due to different yield levels.

Table 7.5. Costs, excluding fertiliser costs, per hectare in different regions (FIM). Costs in Southern Finland = 1.

	Wheat	Rye	Barley	Malting barley	Oats	Oilseed plants	Silage	Hay	Sugar beet
Southern Finland	5636.5 (1)	5259.0 (1)	4454.1 (1)	5099.1 (1)	4398.0 (1)	4791.5 (1)	4410 (1)	4086 (1)	12549 (1)
Central Finland	6124.0 (1.09)	5351.0 (1.02)	4539.1 (1.02)	5184.1 (1.02)	4483.0 (1.02)	4873.5 (1.02)	4410 (1)	4086 (1)	13097.8 (1.04)
Ostro-bothnia	5924.5 (1.05)	5332.5 (1.01)	4499.1 (1.01)	5144.1 (1.01)	4443.0 (1.01)	4848.5 (1.01)	4410 (1)	4086 (1)	12801.8 (1.02)
Northern Finland	6562.0 (1.16)	5559.5 (1.06)	4900.6 (1.10)	5490.1 (1.08)	4844.5 (1.10)	5031.5 (1.05)	4336 (0.98)	4132 (1.01)	13877.0 (1.11)

The use of labour per animal in dairy production is assumed to be the lowest in Ostrobothnia because the average farm size was the greatest in that region in 1995 (Table 7.6). The use of labour per dairy cow in Southern Finland is assumed to be 6%, in Central Finland 8.5%, and in Northern Finland 11.7% higher than in Ostrobothnia. The relative differences in the use of labour per dairy cow between regions are lower than or equal to the differences in the farm size in 1995, which is the first year of the simulation.

In milk production, depreciations on buildings in Northern Finland were assumed 25% higher than in the other parts of the country due to the small farm size. Furthermore, overhead costs per dairy cow were assumed 50% higher than in the other parts of the country. These assumptions can be supported by the study of Rantala (1997), where the fixed costs of milk production were found to be as much as 25% and the overhead costs as much as 50% higher than in other

Table 7.6. Average farm size of dairy farms in the main regions and the assumed difference in labour use per animal. Southern Finland = 1.

	Southern Finland	Central Finland	Ostro-bothnia	Northern Finland
Average farm size *)	11.7	11.38	13.2	11.2
	(1)	(0.97)	(1.13)	(0.96)
Assumed use of labour **)	194 hours	200	183	203.6
	(1)	(1.03)	(0.94)	(1.05)

*): Source: Niemi et al. 1995.
**): Assumed in this study.

Table 7.7. Costs, excluding feed costs, per animal in different regions (FIM). Costs in Southern Finland = 1.

	Dairy cows	Heifers for dairy cows	Heifers for meat	Bulls <15 months	Bulls >15 months	Suckler cows	Breeding bulls	Breeding heifers
Southern Finland	14826.1 (1)	3747.5 (1)	2401.4 (1)	2671.0 (1)	3443.9 (1)	3165.7 (1)	1581.4 (1)	2171.9 (1)
Central Finland	15216.2 (1.03)	3860.9 (1.03)	2437.2 (1.01)	2701.0 (1.01)	3481.4 (1.01)	3342.3 (1.06)	1641.8 (1.04)	2292.8 (1.06)
Ostro-bothnia	14322.8 (0.97)	3672.6 (0.98)	2324.4 (0.97)	2606.8 (0.98)	3363.7 (0.98)	3272.7 (1.04)	1618.8 (1.02)	2246.8 (1.03)
Northern Finland	15932.2 (1.07)	3993.6 (1.07)	2459.2 (1.02)	2719.2 (1.02)	3504.1 (1.02)	3342.3 (1.06)	1641.8 (1.06)	2292.8 (1.06)

regions. One should note, however, that the study of Rantala (1997, p. 35) is based on a rather small sample of dairy farms and thus the results are not representative. It is unlikely that *all fixed costs* were 25% higher in the north than in other part of the country. Fixed costs per animal are not directly proportional to the farm size. Farmers may partly compensate for a small farm size by using smaller tractors and other machinery, for example, compared to larger farms. For this reason, only the building depreciation was assumed to be higher in the north, and the machinery and other depreciations on dairy farms were assumed to be at the same level in the north as in the other parts of the country.

The actual use of labour and capital per hectare and animal in the northern parts of Finland may be larger than assumed here due to difficult natural conditions, like cold and long winter, snowfall, long distances between parcels, etc. There is little statistical or other representative information available, however, on the various factors influencing the production costs in the Northern Finland, and one needs to be cautious in using assumed levels of inputs.

The resulting overall differences in the production costs per animal between regions are relatively small, as can be seen in Table 7.7. No differences in labour and capital use between regions were assumed in pork and poultry production. There is little empirical and representative information, even less than in the case of dairy production, on which such assumptions can be based.

7.2.3. Price of labour

Price of labour is of fundamental importance in the model since it describes the opportunity cost of labour. The opportunity cost of labour is important especially in partial (dis-)equilibrium setting since the other sectors of the economy determining the wage rate are not included. Thus the wage rate, i.e. the price of labour, is exogenous in the model. The price of labour is likely to be different in different regions because the demand for labour is different in different parts of the country. Southern and Western Finland are characterised by better employment possibilities than the sparsely populated eastern and northern parts of the country. All professions and jobs are not, however, equally accessible for farmers. Young potential farmers are more flexible in selecting their job and the source of income than farmers who have already committed to considerable investments necessary for farming.

The problem of determining the opportunity cost of labour in each region was not solved in this study. For simplicity, the same price of labour was used in all regions in the model. The price of labour has been obtained from farm level production cost calculations (MKL 1996a, p. 142). The price of labour in 1995 used in this study is FIM 50 per hour of work and includes additional costs, like social security fees and taxes. The price of labour is subject to inflation since the general nominal wage rate increases in the economy. The inflation of labour and other inputs in ex ante years is a scenario parameter discussed in Chapter 8.

7.3. Feed use of animals

The farms recorded in the sample of the Rural Advisory Centres are slightly larger than the average farms in Finland, and the recorded milk yield per dairy cow per year on these dairy farms is higher than the average milk yield per dairy cow per year in Finland. For this reason, the initial values of the feeding variables have been slightly reduced from the levels suggested by the actual feeding data collected from the farms concerned. This is also necessary in order to adjust the value of some feed inputs to the actual values presented by the total calculations of agriculture. As already discussed above, the composition of the animal diets included in the model are quite representative since the diets are based on a large sample of farm-level data.

The yields of dairy cows reported in MKL (1995b) were decreased by 1,000 kilos in each region in order to adjust the average yield level. Because of this, the aggregate feeding requirements in each region were decreased from the values derived from sample data as well. Strict energy, protein, and roughage requirements were specified, using the feeding recommendations adopted from MKL (1996a), and imposed on the feeding variables. The feeding requirements increase in the model as the yields increase due to increased genetic potential, is exogenous in the model.

The initial feed use of dairy cows is based on sample data from 12,000 farms, and the initial feed use of dairy heifers is based on sample data from 8,400 farms (MKL 1996b, p. 35). The endogenous feeding variables in the model are checked for plausibility by imposing some constraints. In the feeding of dairy cows it is of primary importance to ensure the sufficient intake of energy, protein and roughage. The production capacity of dairy cows as well as other bovine animals, depends on the composition of the diet. If the share of grain-based feed is, some indicators of the protein intake may get values which are biologically unacceptable in the long run (MKL 1996a). Such indicators are constructed in the model in order to check the plausibility of feeding. The share of grain-based feeding should not be increased too rapidly in order to sustain the feasible range of the indicator values. During the simulation runs the values of some indicators have decreased close to the lower limits of the feasible range, but the values are still with the range of the feeding recommendations. It seems that the flexibility constraints imposed on the feeding variables in the model are necessary for preventing too rapid changes in the feeding of bovine animals.

There are three kind of bulls in the model: bulls from dairy cows to be slaughtered at 220 kilos of carcass weight, bulls from dairy cows to be slaughtered at 270 kilos of carcass weight, and breeding bulls from suckler cows to be slaughtered at 310 kilos of carcass weights. The initial feed use of bulls is based on sample data from 3,900 farms (MKL 1996b, p. 35). The diets have been adjusted for the two different carcass weights using the production cost calculations of MKL (1995).

In the feeding of pigs it is important to ensure not only the sufficient intake of energy but also a sufficient intake of protein. Strict constraints are imposed to guarantee the recommended level of protein and energy intakes. The initial diets of pigs have been obtained directly from the pig recording data system of by the Rural Advisory Centres. The initial diets of hens and other poultry have been compiled directly from MKL (1995). The more efficient feed use of breeding bulls have been accounted for in the feeding requirements, i.e. the breeding bulls need less feed per kilo of meat produced than the dairy bulls.

7.4. Processing and transportation costs

The retail prices of individual dairy products (there are 18 different dairy products in the model) are obtained from basic consumer price statistics produced by Statistics Finland. The retail prices of dairy products are slightly different in different regions. Fixed retail and processing margins are used, and they are the same in the whole country. The fixed processing costs mean that efficiency gains should be achieved in the processing industry since wages and other costs are increasing, in nominal terms, due to inflation.

It is difficult to obtain information of the actual dairy processing costs of dairy companies since these companies are reluctant to make such information publicly available. For this reason, the processing costs of dairy products have been calculated on the basis of milk fat and skimmed milk composition of each product, the producer price of milk (roughly FIM 2/kg in 1995), value shares of milk fat and skimmed milk, and the retail margin of milk products.

The composition of each dairy product, i.e. the share of milk fat and skimmed milk in each milk product, has been obtained from the actual dairy products to be sold in a supermarket, and these are presented in Chapter 8. The value of skimmed milk and milk fat in each dairy product can be calculated on the basis of the composition of each dairy product, the value shares of milk fat (60%) and skimmed milk (40%) and the producer price of milk.

The marketing margins (i.e. the difference between the retail prices and the value of raw material, at the producer price level) in Finland have been calculated by Laurinen (1996) and Peltomäki (2000). The marketing margin includes both the retail margin and the processing costs, but the shares of retail margin and the processing cost have not been calculated separately. The retail margins determine the processing costs of each product as the value of raw material of each dairy product is known.

Unfortunately, the retail margins are not public information but proprietary information of supermarket chains. The retail margins, as well as the total marketing margins, of different milk products are very different. In this study, a 20% retail margin is assumed for liquid milk and curdled milk products (8 different products), 38% retail margin for yoghurt products (2 different products), 30% retail margin for cream products (two different products), 33% retail margin for Edam cheese, 40% retail margin for Emmental cheese and other cheeses, 50% retail margin for milk powder, and 2% retail margin for butter. The retail margins have been chosen in order to calibrate the 1995-1996 export volumes of cheese and yoghurts to the actual export levels using a base level of the export cost function (presented in Chapter 6). The function of the export cost function is to prevent large short-term fluctuations in exports, not to calibrate the initial export levels in the beginning of the simulation. Hence, the retail margins of some liquid milk products are adjusted in the calibration. The retail margins of the individual dairy products are not arbitrary in the model, however. For example, the retail margins of butter have been very low or even negative because of the decreasing butter consumption despite the reduced prices (MTTL 2000, p. 43-44). The calibrated retail margins of cheese and yoghurt, on the other hand, should be close to reality since the exports have been profitable for dairy companies, and the export volumes have been quite stable in the 1990s.

When the retail margin is subtracted from the retail prices, the remaining wholesale price includes the processing costs and the value of milk fat and skimmed milk. When the value of milk fat and skimmed milk is further subtracted from the wholesale price, one obtains the processing margin of each dairy product. This margin is kept fixed during 1995-2010. This means that dairy processing firms are able to cut costs in processing, since the prices of labour and other inputs are increasing due to inflation.

The producer price of milk is calculated as a weighted average of the prices of dairy products, which are endogenous in the model. Since the retail prices of dairy products are different in different regions, the producer price of milk may be slightly different in different regions as well.

The processing costs of sugar beets to raw sugar and the processing costs of raw sugar to white sugar have been calculated using the actual retail prices, a retail margin (including taxes), and yield coefficients of the refining process. Using the margins, the price of sugar beet is then calculated from the price of white sugar, which is priced at the retail price level.

Transportation costs of crop products between the main regions as well as the shipping costs when importing or exporting grain in the model have been obtained from Aaltonen et al. (1999). The transportation costs of grain between main regions in the model are FIM 0.075/kg, and the transportation costs of exports and imports are FIM 0.12/kg, according to Aaltonen et al. (1999).

7.5. Parameter estimates of crop yield functions

Results of some yield experiments have been used when setting parameters for crop yield response functions, i.e. how the crop yield changes as a response to changes in fertilisation. Since the yield levels in the experiments do not match the average yield level in each region, some of the parameter estimates need to be adjusted. The adjustment procedure is described in Chapter 6.4.

Initial parameter estimates have been taken from the studies of Bäckman et al. (1997), Heikkilä (1980), Kleemola (1989) and Ylätalo (ed.) (1996). Quadratic yield functions are used in the case of rye, dry hay and oilseed plants. The parameter estimates of the quadratic functions have been obtained from Heikkilä (1980), who used information from fertilisation trials performed in 1969-1978. In the case of potatoes there were no empirical estimates of the crop yield functions available. Parameters estimated for quadratic yield function of barley computed by Bäckman et al. (1997) were taken as initial values. The initial parameter estimates of the quadratic yield functions of silage and grass fodder were taken from Kleemola (1989), who used information of fertilisation trials from years 1978-1988.

As presented in Chapter 6.4, only parameter *b* of equation 6.40 and parameter *b* of equation 6.41, which are the main parameters affecting the fertiliser response, have been taken directly from the fertilisation trials. The other parameters have been adjusted in order to calibrate the crop yield functions to the actual crop yield levels at a certain fertiliser use in each region. The resulting crop yield parameters of the model as well as the initial parameters estimates

Table 7.8. The parameters of quadratic crop yield functions in Southern Finland, support region B.

	Rye	Starch potato	Food potato	Sugar beet	Hay	Silage	Green fodder	Oilseed plants
DREMFIA:								
A	1658.8	17703.2	17881.6	23630.0	1374.2	1182.9	1586.6	1096.1
B	12.34	53.21	53.21	53.21	33.8	24.24	24.24	9.82
C	-0.0289	-0.16392	-0.2270	-0.083	-0.078	-0.0394	-0.0436	-0.0354
Experiments:								
A	2086.0	*)	*)	*)	3089	2821.0	**)	1247.0
B	12.34	*)	*)	*)	33.8	24.24	**)	9.82
C	-0.0171	*)	*)	*)	-0.1189	-0.02	**)	-0.0324

*) No experimental parameter estimates available. The parameter estimates of barley are used as initial values.

**)No experimental parameter estimates available. The parameter estimates of silage are used as initial values.

calculated directly on the basis of the data of the experiments, are presented in Tables 7.8 and 7.9. The parameters are different in different regions since the fertiliser use and crop yields vary between the regions. In Tables 7.8 and 7.9 yield function parameters in Southern Finland, in support area B, are presented.

Table 7.9. The parameters of Mitscherlich crop yield functions in Southern Finland, support area B.

	Wheat	Barley	Malting barley	Oats	Mixed grain	Peas
DREMFIA:						
M	4075.5	3985.9	3909.5	3865.4	3537.9	2582.8
K	0.4442	0.4193	0.3896	0.4343	0.4745	0.4875
B	0.0105	0.0168	0.0168	0.0197	0.0197	0.0197
Experiments:						
M	4956	5217.9	*)	4760.3	**)	**)
K	0.7624	0.828	*)	0.7075	**)	**)
B	0.0105	0.0168	*)	0.0197	**)	**)

*) No experimental parameter estimates available. The parameter estimates of barley are used as initial values.

**) No experimental parameter estimates available. The parameter estimates of oats are used as initial values.

7.6. Parameter estimates of milk yield function

A quadratic milk yield function is used for dairy cows. The use of grain in the feeding of dairy cows is the explanatory variable in the function, as presented in equation 6.29 in Chapter 6. The role of the milk yield function is to capture the part of milk yield development that is due to the increasing use of grain in feeding. The parameters of the function are estimated from the experimental data of Sairanen et al. (2000), who tested the effect of increasing grain feeding levels on milk yield in a sample of 36 cows. The amount of grain-based feedstuffs, measured as dry matter, was gradually increased, at steps of 2.5 kilos, from 5 kilos up to 15 kilos per dairy cow per day. The amount of grain-based feedstuffs was increased by 2.5 kilos once a month. The total length of the experiment was 5 months. The study was not concerned with the potential long-term negative side effects of the high share of grain in feeding, but only the short term response of milk yield to the increased grain used in feeding. The average yield level and the total amount of feedstuffs in the experiment of Sairanen et al. (1999) were clearly higher than the average yield level in Finland. The starting level of grain-based feedstuffs (5 kg/dairy cow /day), however, is very close to the level of the actual use of grain-based feedstuffs in Finland, except in Northern Finland, where more than 6 kilos of grain-based feedstuffs are used by dairy cow.

The experimental data of Sairanen et al. (1999) are used in this study as follows. The parameters of the quadratic function appearing in equation 6.29 are estimated after adjusting the daily yield levels to the average yield level at the point of 5 kilos of grain-based stuffs. This amount of grain in the daily diet of dairy cows is very close to the actual average diet of dairy cows (except in Northern Finland, where the amount of grain-based feedstuffs is more than 6

Table 7.10. The impact of grain-based feedstuffs on milk yield of dairy cows according to experimental data of Sairanen et al. (1999) and the adjusted data used in this study.

Level of grain-based feedstuffs (dry matter)	5.0 kg	7.5 kg	10 kg	12.5 kg	15 kg
Milk yield per cow per day *)	26.3	27.8	29.5	30.5	30.6
Increment from 5.0 kg level *)	0	1.5	3.2	4.2	4.3
Milk yield per dairy cow **)	16.1	17.0	18.0	18.6	18.7
Increment from 5.0 kg level **)	0	0.9	2.0	2.6	2.6

*) Sairanen et al. 1999.
**) Adjusted data

Table 7.11. Regression results when regressing milk yield function $F = A + B*X + C*X^2$ to the adjusted data of Table 7.10.

	A	B	C
Estimate	-1200.9	0.7657	-6.7 E-5
Standard error	51.42	0.133	1.8 E-6
t-value	23.4 *)	5.73 *)	3.70 **)

*): Significant at 97.5% confidence level
**): Significant at 95% confidence level.

kilos per cow per day). The high yield levels of the experiment of Sairanen et al. (1999) were adjusted to the average yield level by multiplying by factor 0.61. The relative effect of grain in the yield level, however, remained as reported by Sairanen et al. (1999). The actual experimental data of Sairanen et al. (1999) and the adjusted data are presented in Table 7.10.

The parameters of the milk yield function were estimated using the adjusted data in Table 7.10. In particular, when modelling the increments of yields due to increased use of grain-based feedstuffs in feeding, the increments in yields in the adjusted data are used in the estimation. The parameters were estimated by using standard ordinary least squares. According to the estimation results, the quadratic function fits the data quite well, and the parameter estimates are consistent with relatively small standard errors. The regression results, with 3 degrees of freedom, are presented in Table 7.11. Despite the low degree of freedom, the parameter estimates are significant at 95% confidence level.

8. The chosen scenario parameters

The chosen scenario parameters are presented in this chapter. The scenario parameters presented in Chapters 8.1-8.4 apply to both the base model and the extended model, while the parameters presented in Chapters 8.5-8.7 apply only to the base model. Hence, the Chapter 8.5 presents the efficiency scenario, used in the application of the base model (Chapter 9). The sunk costs presented in Chapter 8.6 are related to the efficiency scenario used in the base model. The flexibility constraints and sensitivity scenarios used in the base model application are presented in Chapter 8.7.

8.1. Policy scenarios

There are two policy scenarios used in this study. The *base scenario* represents the continuation of 1999 policy while *Agenda 2000* represent the Agenda 2000 CAP reform of EU combined with some changes in national support. Hence Agenda 2000 represents the actual policy to be implemented in Finnish agriculture until 2006. Only the policy parameters are different between the base scenario and the Agenda 2000 scenario.

According to the Agenda 2000 CAP reform, grain intervention prices, i.e. prices of wheat, rye and barley, are decreased by 15% until the end of 2001 in two equal price reductions taking place in 2000 and 2001. It is assumed that these price reductions affect directly the market prices in Finland and in the EU. Oats prices are also decreased by 15% until the end of 2001 even if oats is not part of the intervention system because oats is a substitute for barley in feeding. The price reduction of grains is partly compensated for through increased direct payments per hectare. The area payment is increased in two steps from €54 to €63 per tonne, multiplied by the historic reference yields which are different in different support areas. This represents, on the average in the EU, a 50% compensation for the price cut. The same rates apply for set-aside. In addition, Finland was granted an additional subsidy of €19 per ton, to be added to the CAP payment, as compensation for the specific drying costs of cereals and oilseeds due to unfavourable natural conditions.

The basic compulsory set-aside rate is fixed at 10% during 2000-2010. The oilseeds area payment is to be cut in three stages to align with the cereals payment, i.e. from €81.74 per ton down to €63 per ton in 2002. Silage grass was also included in the CAP base area (the maximum area for which the CAP support can be paid) from 2000. The basic cereals reference yield will apply to these payments. The base area for silage grass is 200,000 hectares while the total CAP area of Finland is 1.6 million hectares. If the CAP base area is exceeded (this is possible because the silage grass area has been more than 300,000 ha in recent years), the CAP support for the silage grass is cut by an amount proportional to the relation between the base area and the actual area (European Commission 1999). In the model the CAP payment is decreased if the CAP or silage base area is exceeded at the previous year. Making the CAP payment directly dependent on the current year's area would imply 0-1-variables into the model which would increase the computational burden of the model and have a negative effect on the reliability of the solution.

Intervention prices of butter and skimmed milk powder will be decreased by 15% in three equal steps during 2005-2007. In this study it is assumed that the producer prices of milk will decline by 15% during 2005-2007, too. The milk quota regime is extended to 2006. However, a 1.5% increase in quotas will be implemented in 2005-2007 in parallel to the price reductions. This means no change in quotas until 2005. The price reductions of milk will be compensated for by payments per quota tonne of each producer. In the model this payment is assigned per dairy cow by dividing the national quota by the last year's total of dairy cows. Since the number of dairy cows will decrease because of the fixed quota (until 2005) and increasing milk yield per dairy cow, the compensation payment per dairy cow will gradually increase. €5.75 per quota ton is paid in 2005, €11.49 per quota ton in 2006 and €17.24 per quota ton in 2007 and in the following years. In addition to this compensation, "national envelopes" are paid for cattle farms from the year 2005. Each member state of the EU has some freedom in allocating the money in the national envelopes to the specific animals. In Finland the national envelope is €4.7 million in 2005 and is increased linearly to €18.6 until 2008 (European Commission 1999). It is assumed that a major part of the money in the national envelope will be allocated to specialised beef farms where the profitability is relatively low compared to dairy farms. However, the national envelopes are rather marginal, in terms of value, compared to other support regimes.

Beef intervention prices are cut by 20% in three equal steps over the period 2000-2002. This will give a basic price of €2,224 per tonne while the 1999 beef intervention price was €2,780 per ton. This price reduction is assumed to apply to market prices of beef as well in this study. The price reduction is compensated for by a beef premium rising to €210 per head of bull payable once in a lifetime of a bull. The premium paid for suckler cows rises to €200 per head. Steers, which are rare in Finland, are paid €150 per head twice per lifetime. In addition, a new slaughter premium of €80 is introduced for bulls, steers, dairy cows, suckler cows and heifers over the age of eight months, and of €50 for calves of more than month and less than 7 months, with an upper limit of 160kg (European Commission 1999).

Extensification premium system was slightly changed from the 1999 system in the Agenda 2000. In 1999 an extensification premium of €52 per hectare of forage area (consisting at least 50% pasture land) was paid if animal density, calculated in livestock units per hectare using specific coefficients for each animal type, did not exceed 1.0 per hectare. €36 was paid per forage hectare if the animal density was below 1.4. In 2000 and 2001, however, €66 per hectare is paid if the animal density is below 1.6, and €33 if the animal density is between 2.0 and 1.6. From 2002 €80 is paid per forage hectare if the animal density is less than 1.4 and €40 if the animal density is between 1.8 and 1.4 (European Commission 1999).

Support for less favoured areas (LFA), paid jointly by the EU and Finland, can be paid in the whole country from the year 2000. Earlier the support area A was excluded from the LFA-support. In the year 1999 the LFA support per hectare was between FIM 1,011-FIM 1,027 in Finland. In 2000 LFA-support is FIM 890/ha in support area A, FIM 1,190/ha in support areas B and C1, and FIM 1,250/ha in support areas C2-C4. In this study it is assumed that the LFA support will not change after 2000.

Environmental support, paid jointly by the EU and Finland, amounted to FIM 1.7 billion in 1999. The sum of environmental support decreased to FIM 1.4 billion in 2000. This was due to changed regulations concerning the share of the environmental support to be paid from the national funds. The environmental support are assumed to be fixed after year 2000.

National aids paid for animal production is Southern Finland – in support areas A and B – were agreed by the EU Commission and the State of Finland in January 2000. The agreement applies to the end of the year 2003. Aid for milk and beef production decreases 3.5% annually until 2003 from the maximum allowable level of the year 1999 (the maximum allowable support levels were not always paid in 1999, however). The price support for milk in Southern Finland decreases from FIM 0.37/kg down to FIM 0.335/kg until 2003. There will be no changes in the price support for milk in support areas C1-C4. Consequently, the price gap between areas A and B, and area C1 (which has the lowest milk price support of FIM 0.51/kg of the all support areas C) increases from FIM 0.14/kg to FIM 0.175/kg until 2003. Support for pork, egg and poultry production are reduced by 4.5% annually until 2003. The continuation of the animal support for southern Finland, if there will be any, will be decided in negotiations between the EU Commission and Finland in 2003. However, in this study the level of the national aid to be paid for animal production are assumed to be fixed at the 2003 level after 2003.

It is assumed that the nationally financed northern aid (paid only in areas C) will remain at the level of 2000. This level is slightly higher than the 1999 support level due to the abolition of the transitional aid in 2000. The level of northern aid is higher in areas C3 and C4 in the very northern parts of Finland than in areas C1 and C2 in the central parts of Finland.

Some other supports, of minor importance, are assumed to remain fixed after 2000.

The Agenda 2000 price reductions of cereals are likely to have some indirect effects on the prices of pork, poultry meat and eggs. Decreasing cereals prices influence feeding costs of animal production. In the dairy and beef sectors, however, the cereal prices have less effect on feeding costs and product prices than in pork and poultry sectors because dairy farms also use roughage in the feeding of animals and because of the milk production quotas. In some studies analysing the effects of Agenda 2000 at the EU level it is concluded that prices of pork and poultry meat are going to decrease by more than 15%. This is explained to be a result of the expected effect of beef price reduction on the demand of pork and poultry meat. The decrease in the producer prices of beef, if they influence consumer prices, may result in an increase in the demand of beef which may deminish or even stop the upward trend in the demand of pork and of poultry meat. This, together with the increased profitability of pork production due to decreased cereals prices, may result in excess supply and decreasing pork and poultry prices (Agra Europe 1999). However, if the reduced beef price has little or no effect on the demand of pork and poultry meat, there may be only a slight decrease in the prices of pork and poultry meat due to the decreased grain prices. In this study, a 9% reduction in the prices of pork, poultry meat and eggs is assumed. Such a moderate price reduction assumption can be motivated by the fact that there has been a strong upward trend in poultry consumption in the EU. In Finland this trend has been exceptionally strong in recent years due to the low level of consumption before the EU integration. The beef consumption in Finland has been quite unresponsive to price changes in recent years (MTTL 2000, p. 43-44). The consumption of beef increased only 1-2% in 1995-1996 even if the consumer prices decreased by more than 20% from 1994 to 1996. The downward trend of beef consumption has continued after the price shocks in 1995 and 1996. From 1994 to 1999 the beef consumption has decreased by 1%. No price shocks in consumer prices comparable to 1995 and 1996 can be expected due to the Agenda 2000 reform.

8.2. Consumption trends and elasticity values

There are strong trends in the consumption of different food items (MTTL 2000, p. 43-44). Even price reductions of 10-25% have resulted in small changes in the consumption of some food items (like butter and beef), while the consumption of pork and eggs have increased, at least temporarily, because of the price reductions of 23 and 65 percents, respectively. No price shocks in consumer prices comparable to 1995 and 1996, however, can be expected due to the Agenda 2000 reform. The relative magnitude in the decrease in producer prices was much higher in the producer prices in 1995 than in the consumer prices since the producer price is only one element in the consumer price. It is very likely that the price reductions of Agenda 2000 will result in only minor changes in consumer prices. For this reason, the same trends of consumption are assumed in both policy scenarios. The allowable ranges of consumption from the given trend values presented in Tables 8.1-8.3 are quite narrow in the case meat, but there is still scope for change in the meat consumption in the model. Thus the consumption of meat as well as other products may change slightly in the model because of the price changes.

Since there is some evidence that consumers prefer some domestic food items to the imported ones (Finfood 1999), the demand functions of some domestic products have been set to a higher price level than the demand function of the imported products. The demand function of domestic beef has been set to a level that is 7% higher than the demand function of the imported beef. The demand function of domestic pork has been set to a price level that is 4%

Table 8.1. Consumption of dairy products included in the DREMFIA model in 1995 and the estimated trend of consumption, allowable range of consumption in the model, as well as the price elasticity of demand, substitution elasticity between domestic and imported products, and the share of skimmed milk and milk fat in the milk products in the model.

Product	Consumption (mill.kg)	Annual trend in consumption (%)	Lower and upper bounds of consumption (%)	Price elasticity of demand	Substitution elasticity between domestic production and imports	Share of skimmed milk (% milk equivalent)	Share of milk fat (%)
Fat milk	123.8	-1	0.5	-0.3	10	96.1	3.9
Light milk	403.5	-0.5	0.5	-0.3	10	98.5	1.5
Skimmed milk	144.6	0.5	0.5	-0.3	10	99.5	0.5
Other liquid milk	71.4	0	0.5	-0.3	10	97.7	2.3
Light curdled milk	43.5	0.2	1	-0.3	8	99.5	0.5
Curdled milk	43.5	0.2	1	-0.3	8	97.75	2.25
Light yoghurt	38.5	0.5	2	-0.5	4	99.5	0.5
Yoghurt	38.5	0.5	2	-0.5	4	98.0	2.0
Light sour milk	13.8	0	2	-0.5	3	98.2	1.8
Sour milk	10.0	0	2	-0.5	3	90.0	10.0
Light Cream	10.0	0	2	-0.6	6	85.0	15.0
Cream	24.5	-0.2	2	-0.6	4	62.0	38.0
Ice cream	72.3	0.5	4	-0.7	4	97.0	3.0
Milk powder	7.2	0	1	-0.2	4	1090.0	0
Edam	35.0	0	2	-0.6	2.2	1090.0	18.0
Emmental	20.0	1	2	-0.9	2	1090.0	27.0
Other cheese	21.5	1.2	2	-1	4	1090.0	32.0
Butter	30.0	-0.5	1	-0.4	4	0	81.34

higher than the price of the imported pork. Also, the demand function of domestic poultry meat has been set to a level that is 2% higher than the price of the imported poultry meat. These preferences for domestic meat are assumed to be persistent and they are taken into account when updating the demand function each year to the trend consumption level.

The elasticities of substitution between domestic and imported products influence the shifts of consumption between domestic and imported products. The greater the substitution elasticity the more homogenous are the domestic and imported products. Thus the low substitution elasticity values, like those of beef, for example, presented in Table 8.2, imply considerable frictions in the shift of consumers from the domestic to the imported product, or from the imported product to the domestic product. This means that imports may increase quite slowly over time even if the imported products were considerably cheaper than the domestic ones.

The consumption trends presented in Tables 8.1-8.3, which have not been estimated using statistical methods, explain quite well the actual consumption trends in the 1990s. The consumption trends presented in Table 8.1 are assumed to hold until 2010. Some upper and lower bounds for the consumption from the given trend are determined. In the case of liquid milk, for example, the actual annual variations in the consumption have been quite small. In some cases (like ice cream), however, the annual variations are somewhat greater.

A priori knowledge of the special characteristics of the imported and domestic products have been used when giving initial values for the substitution elasticities. Then the elasticity values have been adjusted to get a better fit to the actual import levels. Such a procedure is common in many international trade

Table 8.2. Consumption of meat and eggs in 1999 and the estimated consumption trends, upper and lower bounds around the trend value, price elasticities of demand, as well as substitution elasticities between the domestic and the imported products.

	Consumption (mill. kg)	Annual trend in consumption (%)	Lower and upper bounds in consumption (%)	Price elasticity of demand	Substitution elasticity between domestic production and imports
Beef	95.9	-1	2	-1.2	1.05
Pork	175.4	0	2	-1.1	1.05
Poultry meat	64.3	+2	2	-1	2
Eggs	50.5	0	3	-0.6	5

Table 8.3. Consumption of crops (feed use excluded) in 1995 and an estimated consumption trend, lower and upper bounds around the trend value, price elasticities of demand, as well as substitution elasticities between the domestic and the imported products.

	Consumption (mill. kg)	Annual trend in consumption (%)	Lower and upper bounds in consumption (%)	Price elasticity of demand	Substitution elasticity between domestic production and imports
Wheat	381.6	0	2	-0.3	1.9
Rye	80.8	0	1	-0.2	1.9
Barley	9.8	0	1	-0.1	2
Malting barley	157.4	0	2	-0.2	2
Oats	30.6	0	1	-0.1	3
Peas	7.7	0	2	-0.2	3
Starch potato	246.2	0	1	-0.2	2
Food potato	304.2	0	3	-0.2	3
Oilseeds	73.4	0	1	-0.2	3
Sugar	196.2	0	1	-0.4	7

models heavily built on Armington assumption, specific functional forms, and the estimates of the substitution elasticities (van Tongeren et al., p. 16-17). The values of the substitution elasticities have not been estimated from empirical data, because such an estimation requires a lot of work and there have not been enough resources in this modelling exercise for the estimation. The time series data of prices and quantities of some very specific imported food items are also difficult to get from quite aggregated import statistics. It is also very likely that many estimated values would serve only as initial values and adjustments of many substitution elasticity values would be needed in order to calibrate the imports in the model closer to the actual data.

The lowest substitution elasticities between domestic and imported products have been set for beef and pork. There have been considerable imports and exports of beef and pork in recent years, which can be explained only by very low values of the substitution elasticity. In fact, even the value 1.05 of the substitution elasticity does not yield as high import and export levels of beef and pork in the model as is the case in reality. As already noted in Chapter 6.3, the substitution elasticity must be always be greater than 1. Substitution elasticity values very close to 1 should be avoided, however, because of possible computational problems. In the case of beef and pork it is difficult or even impossible to replicate the actual import and export levels exactly only by adjusting the substitution elasticity values. Nevertheless, the average import levels can be replicated in ex post years 1995-1999, but not all the annual variations in the imports. It is possible that some information is lost when using annual average import prices and quantities. It is also possible that the demand function specification is too simple to explain the annual variations in food demand and imports. There are no stocks in the model, either, while the changes in stocks may be one reason for the fluctuating import levels in 1995-1999. There may be also purely random factors which cause fluctuations in imports.

The substitution elasticity values of bread grain have been given quite low values as well. This is due to the specific cereal varieties cultivated in Finland. There is a difference in the specific characteristics (like those influencing baking) of rye and wheat cultivated in Finland compared to wheat and rye cultivated in other countries in the EU. Malting barley cultivated in Finland also has some characteristics different from the imported malt in beer brewing. Thus the substitution elasticity values between the domestic and imported cereals are lower than those of, for example, the milk products.

It turns out that the outcome of the DREMFIA-model is not very sensitive to the substitution elasticities between imports and domestic products, or to the price elasticities of demand. This does not meat that the substitution elasticity values would have no effect on the imports. The substitution elasticity values affect imports but not to the extent that small changes in the substitution elasticities would change the imports drastically. On the contrary, according to the test runs performed by Lehtonen (1996, p. 96-98), the variations in the substitution elasticity values result in smooth and continuous changes in imports in the DREMFIA model. In many cases the level of imports and domestic production turn out to be quite robust to substitution elasticity values. This is true especially if consumers are assumed to prefer domestic products to imported products. Given some preference to domestic products over imports, it was found that substitution elasticity values had no large effects on the imports, even if the effect of substitution elasticity on imports is cumulative over time. Oilseeds production, however, was found to be sensitive to the substitution elasticity values. This is partly due to the fact that oilseeds production was only profitable in Southern Finland in the test runs performed by Lehtonen (1996), and oilseed production decreased in all other regions irrespective of the substitution elasticity values. Hence, increasing imports caused decreasing oilseeds prices, and sufficiently large substitution elasticity values resulted in such low prices that oilseeds production became unprofitable in Southern Finland, too. Thus there was a sudden drop in the oilseeds production in Southern Finland, where most of oilseeds is produced in Finland, when the substitution elasticity values were given larger values than a certain threshold value.

In the case of clearly unprofitable production the substitution elasticity values determine to a large extent how easily the domestic production is replaced by imports. Comparing the ex post simulation results to the actual import data one may choose the substitution elasticity values that explain, at least approximately, the actual development of imports. Since agricultural policy analysis is made by comparing the outcome of the different policy scenarios, slightly different values of the substitution elasticity should not affect qualitative policy conclusions even in the case of oilseeds, since the same substitution elasticity values are used in all policy scenarios.

In the DREMFIA-model the choice between products, like beef and pork, and between imported and domestic product, like domestic pork and imported pork, is made between the agricultural products only. In many general equilibrium models built on Armington-assumption the representative consumers also choose between food products and various non-food products. In those models the substitution elasticity values play a far more dominant role than in the DREMFIA-model, where the total demand (the total demand of the domestic and the imported product) is exogenous. Hence, the substitution elasticities influence only the substitution between the imported and domestic product in the DREMFIA model. The total demand of each product is given only narrow bounds from a given trend value, and the substitution elasticity, together with the price elasticity of demand, have little effect on the total demand of each product.

There is, however, a need for econometric estimates for the substitution elasticities. Such estimates could be compared to the calibrated estimates. The estimation and the analysis of statistical properties of the estimates are subject of a further study. It depends on the availability and statistical properties of data if statistically significant estimates can be calculated.

8.3. Prices of primary inputs and productivity development

The prices of primary inputs used in agriculture are assumed to rise by 1.8% annually, on the average. The fertiliser prices are assumed to remain fixed. The prices of industrially processed feed is assumed to rise only 1% per year as a result of fixed cereal prices in the base scenario. When the cereal prices change as a result of Agenda 2000 in 2000 and 2001, however, the prices of industrially processed feed change as well. The other costs in feed processing, however, may increase slightly due to the inflation of 2% assumed for all the other inputs in the economy.

It is also assumed that agriculture cannot influence the EU price level, which is determined in the EU market. Thus inflation does not affect the product prices in the model. The crop yield level, however, is assumed to increase very slowly. The crop yield level is assumed to grow linearly by an amount which is 0.5% of the crop yield trend value in 1995. For example, the crop yield level of barley in Southern Finland increases only by 20 kg/ha per year. The price relation of fertilisers and crop products, however, affects the crop yield level in the model. Thus the slow progress in crop yields reflects the increased crop yield potential, not necessarily the actual increase of yields. The Agenda 2000 price reductions, as well as possible domestic price changes, affect the fertilisation and crop yield levels. Slow progress in the yield potential is assumed due to the fact that low crop prices compared to production costs give little, if any, incentive for farmers to increase the crop yields.

The milk yield potential, i.e. the scalar parameter of the milk yield function, will increase linearly at the rate of 110 kg/dairy cow/year. If there are changes in feeding, the actual milk yield may increase at a different rate. The piglets per sow also increase linearly in the model. The rate of piglets per sow is assumed to increase at the rate of 0.24 piglets per sow, which is close to the trend value in the 1990s. This means that the average number of piglets per sow will increase to more than 20 until 2006. The production of eggs per laying hen increases linearly by 0.24 kg/hen/year in this study.

8.4. Parameters of export cost functions

Export cost functions are calibrated by adjusting the slope of the export cost function in order to replicate the actual exports in 1995-1999. If the export volumes from each region change from the previous year, export costs (i.e. the transportation and marketing costs) will also change. If there is no change in the exports from the previous year, the export costs remain at the base level, which is FIM 0.08/kg for crop products and FIM 0.16/kg for other products. However, all annual fluctuations in the exports cannot be replicated, but only the average

Table 8.4. The slopes of the export cost functions.

Product	Slope	Product	Slope
Wheat	0.99	Beef	5
Rye	0.99	Pork	5
Malting barley	0.99	Poultry meat	5
Barley	0.5	Eggs	0.9
Oats	0.5	Ice cream	2
Peas	0.25	Milk powder	1
Food potatoes	0.9	Edam	1
Starch potatoes	0.7	Emmental	3
Oilseeds	0.5	Other cheese	2
Sugar	0.5	Other dairy products	0.8

level of exports in 1995-1999. After 1999 the slope of the export function is kept on the calibrated level until 2010. The slopes of the export cost function are presented in Table 8.4. High slope values have been used for some products in order to prevent large fluctuations in the exports. Such fluctuations may appear in the model since the EU price level is fixed and the exported products are homogenous with the imported products, i.e. the exported products are not differentiated on the EU markets. The Armington assumption applies to only the differentiation between imports and domestic products at the domestic markets in the model.

8.5. Increase in the efficiency of production

In this study increasing the efficiency in production refers to decreasing use of labour and capital per hectare and animal. The exogenous target levels of production efficiency are presented in Tables 8.5 and 8.6. The use of certain inputs per hectare and animal decreases non-linearly as presented in equation (6.40). This means that the increase in production efficiency becomes slower the greater the farm size.

If the increase in the production efficiency presented in Tables 8.5 and 8.6 were a result of the growing farm size only, the relation between farm size and the production costs presented in equation (6.40) would result in an increase of the average farm size from less than 25 hectares in 1999 to 50 hectares until 2006, and close to 60 hectares until 2010. Similarly, the average size of dairy farms would increase from 15.5 cows per farm up to 28 cows per farm in 2006,

Table 8.5. Change in the average use of inputs (%) per hectare and animal from 2000 to 2006 and 2010.

	Crop production		Dairy production		Beef production		Pork production		Poultry meat and egg production	
	2006	2010	2006	2010	2006	2010	2006	2010	2006	2010
Variable costs – labour, medicine, maintenance, etc. (does not include feeding or fertiliser costs)	-6.8	-10.3	-5.9	-8.9	-9.3	-13.8	-14.4	-21.2	-20	-28.8
Fixed costs – depreciations, interests, etc.	-4.5	-6.8	-4.0	-6.1	-4.5	-6.8	-9.3	-13.8	-11.8	-17.5

Table 8.6. Change in the average use of inputs (%) per hectare and animal from 1995 to 2000 and 2006.

	Crop production		Dairy production		Beef production		Pork production		Poultry meat and egg production	
	2006	2010	2006	2010	2006	2010	2006	2010	2006	2010
Variable costs – labour, medicine, maintenance, etc. (does not include feeding or fertiliser costs	-7.8	-14.1	-6.8	-12.3	-10.6	-18.9	-16.4	-22.3	-22.3	-37.9
Fixed costs – depreciations, interests, etc.	-5.1	-9.4	-4.6	-8.5	-5.2	-9.4	-10.6	-18.9	-13.5	-23.7

and to 32 cows per farm until 2010 if the efficiency gain presented in Tables 8.5-8.6 were to result from the increased farm size only. The average size of pig farms specialising in piglet production would grow from 40 sows per farm to more than 60 sows per farm until 2006 and close to 90 sows until 2010. The average size of pig farms specialising in fattening pigs would grow from 200 pigs per farm in 1999 up to 500 pigs per farm until 2006 and to more than 600 pigs per farm until 2010. In poultry production the average farm size would double until 2006, if the presented exogenous change in the production efficiency was only the result of the growing farm size. In egg production such a rapid growth in the production efficiency would result in the average farm size of 5,200 laying hens until 2006 and in 6,600 laying hens until 2010.

8.6. Sunk costs and investment aid

Exogenous technical change and efficiency development due to investment activities implies sunk costs. As already presented in Chapter 6, the share of sunk costs in the model decreases from the 1999 level down to zero until 2010. This is due to heavy investments in 1996-1999 which affect high sunk costs in 1999-2005. Later, however, there are increasing needs for investments since the production equipment built and invested in the late 1980s is wearing off. The opportunity value of capital, however, is neglected even if its value is considerable in the Finnish agriculture. This means that there is always some “excess” production in the model compared to the economic equilibrium, when all costs of production are covered by the revenues. All the building and machinery costs which constitute a major part of the fixed costs in the Finnish agriculture, however, are included in the model until 2010. Before 2010 the production will, because of sunk costs, respond sluggishly to exogenous changes in prices and support.

The level of sunk costs is adjusted in order to calibrate the model to follow the production in 1995-1999. High sunk costs are needed in order to replicate the production level of some products, like pork, for example. The high level of sunk costs is regarded as a consequence of the investment activity during that time, as well as the heavy investments in the late 1980s without much alternative use.

Investment aid can be included in the sunk costs. The investment aid paid by the State need not be covered by the farm revenues and thus farmers can neglect part of the fixed costs. Thus the level of building and machinery costs are never fully taken into account in the model, but only to the level of the unsubsidised fixed costs until 2010.

The share of sunk costs of the all fixed costs and the share of fixed costs taken into account in the model are presented in Figures 8.1-8.2. One can see that there are some differences in the share of fixed costs of the different production lines. This is because the level of fixed costs taken into account in the model, and thus the level of sunk costs, was adjusted in 1995-1999 in order to replicate the actual production levels. Only slight adjustments in the sunk costs were needed in the cases of crop production, dairy production and beef production in order to replicate the actual production activity levels.

In the case of pork and poultry production, however, considerable adjustments in the sunk costs were made in order to replicate the actual production activity levels. The market prices of pork decreased drastically in 1998 while the production went up due to heavy investments in 1997-1998. Thus the sunk costs explain the increasing production in 1998 despite the decreasing market prices, as well as time lags between the investment decision and the actual production. Similar reasoning applies to poultry production. Large investments to poultry production facilities increased production despite fluctuating market prices.

The level of sunk costs remains relatively steady in all production lines after 2000. There is some decline, however, in the level of sunk costs because the production facilities built in the late 1980s are wearing off and there is an increasing need for investments. Decreasing share of sunk costs and increasing share of fixed costs means that gradually more and more fixed costs are taken into account in the farmers' decision-making, until only investment aid, as well as the opportunity value of capital (not included in Figures 8.1 and 8.2) are neglected. The average level of investment aid in different production lines were calculated on the basis of statistics of the paid investment aid for agricultural investment projects compiled by the Ministry of Agriculture and Forestry.

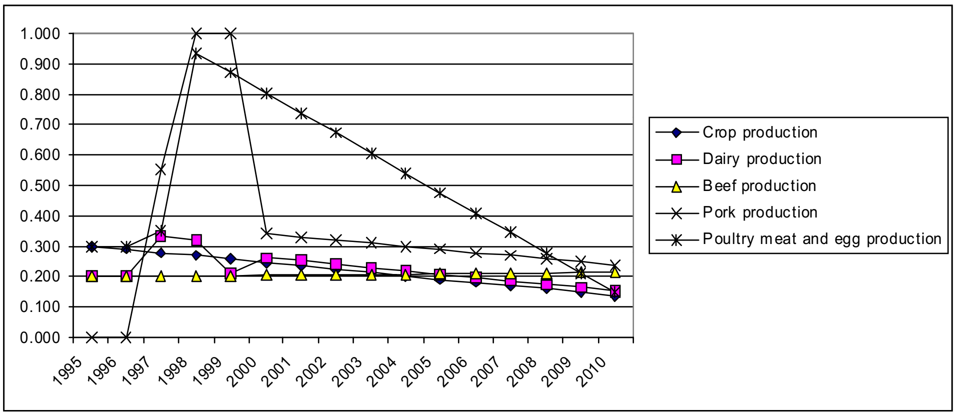

Figure 8.1. The share of sunk costs of all fixed costs until 2010.

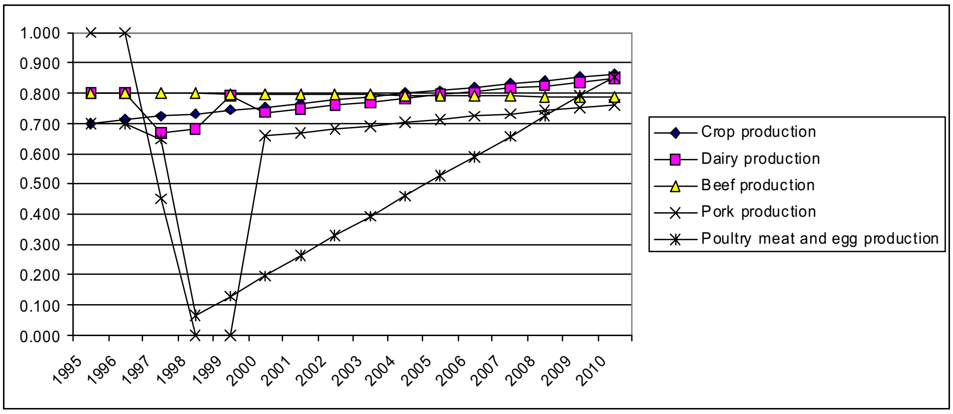

Figure 8.2. The share of fixed costs taken into account in farmers' decision-making.

Table 8.7. Estimated share of investment aid of the total investment expenditure (%) and the share to be paid by farmers (%).

	Dairy production facilities	Beef production facilities	Pork producton facilities	Poultry production facilities	Grain drying facilities	Other machinery and equipment
Share of aid	27	21	23	15	26	14
Share to be covered by farmers	73	79	77	85	74	86

However, all investment projects are not eligible for aid, for a number of reasons. Because of this, it is assumed that 80% of all investment costs of agriculture will be subsidised. The resulting levels of aggregate investment aid, measured as a share of aid of the total cost of the investment projects, are presented in Table 8.7.

8.7. Flexibility constraints and sensitivity scenarios

Annual changes in the values of the production variables, like the number of animals, hectares of crops, and the feeding variables representing the use of each feed-stuff in the feeding of each animal, are bounded by the so-called flexibility constraints in order to ensure the realism of the model. In addition to the flexibility constraints of the base model, however, four sensitivity scenarios (Sensitivity1-4) are used to analyse the sensitivity of the model results to the given flexibility constraints. In Sensitivity 1, the allowable range of change of the production variables is *increased* by 25%. In the sensitivity scenarios 2 and 3 the annual allowable range of change of the production is *increased* by 50% and 100%, respectively. In the sensitivity scenario 4 the allowable range of the production variables is *decreased* by 50%. The given limits for change can be compared to the maximum and average annual changes in the actual time series data. Different flexibility constraints and the resulting allowable range given for the decision variables can be understood to represent the extent of optimising behaviour of farmers.

The maximum rates of annual change of hectares of different crops are given in Table 8.8, and Table 8.9 presents the maximum rates of annual change of the number of different animals as well as the feeding variables. In Table 8.8 one can see that rye areas have been very volatile in Finland. This is because of the changing weather conditions during the sowing period which are sometimes quite unfavourable. It is also likely that changes in the profitability of rye cultivation affects the rye areas. In 1995-1999 the profitability of rye cultivation, however, has changed only slightly. Consequently, the great variations in the annual areas under rye can be assumed to result primarily from the changing weather conditions rather than the farmers' response to economic conditions. It is clear, however, that rye is more sensitive for economic conditions than feed crops, for example, which are dependent on animal production. Farmers may easily switch to other crops if rye is relatively less profitable than other crops. Hence, it is reasonable to impose a relatively wide annual allowable range for rye, but not the range corresponding to the maximum annual change observed. In the model it is the relative profitability between crops which determines the areas under different crops, not the changing weather conditions.

The allowable annual ranges for grass areas are much higher in the base model than the actual observed changes in grass areas. This is because the crop statistics of silage, hay, and pasture are less reliable than those of the other crops, and there may be a discrepancy between the feed diets of cattle and the grass areas. This is because silage, for example, can be harvested from hay or pasture areas as well, and this does not show in the aggregate statistics. Hence, the allowable range for grass areas is relatively wide in order to avoid computational infeasibility because of the feed balance constraints.

One should note that the decrease of the number of animals may, in some cases, be larger than the increase. For example, in the base model the number of dairy cows is allowed to decrease 6% per year and increase only 3% per year. This is due to the fact that decreasing the number of animals is often easier than increasing. There are some biological constraints involved in increasing the number of animals, especially if the fertility of heifers or sows, for example, is not good. In general, there is a greater risk in increasing the number of animals since the future revenues from an additional animals are uncertain, while revenues obtained when slaughtering an animal are rather certain since the market prices of meat are known. Thus one may also include risk aversion behaviour in the upper and lower bounds of the numbers of animals, but there are also other factors that restrict large annual changes in the number of animals.

There are cases in reality where farmers have not been able to take as many animals to slaughterhouses as they would have desired because of the limited

Table 8.8. The maximum rates of annual change imposed on the decision variables representing hectares of crops (%).

Crop	Base	Sensitivity 1	Sensitivity 2	Sensitivity 3	Sensitivity 4	Maximum annual change (%) 1994-1999	Average annual change (%) 1994-1999
Wheat	30	37.5	45	60	15	16	12
Rye	40	50	60	80	20	242	74
Barley	10	12.5	15	20	5	7	3
Malting barley	30	37.5	45	60	15	N/a	N/a
Oats	10	12.5	15	20	5	14	5
Other grains	40	50	60	80	20	31	14
Silage grass	20	25	30	40	10	10	4
Pasture	20	25	30	40	10		
Hay	50	62.5	75	100	25	4	2
Potatoes	20	25	30	40	10	5	3
Starch potatoes	30	37.5	45	60	15		
Sugar beet	20	25	30	40	10	28	13
Oilseed plants	30	37.5	45	60	15	10	3
Set-aside	30	37.5	45	60	15	7	3
Green set-aside	20	25	30	40	10	56	23

Table 8.9. The annual upper and lower bounds imposed on the decision variables representing the numbers of animals (%).

	Base		Sensitivity 1		Sensitivity 2		Sensitivity 3		Sensitivity 4	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Dairy cows	6	3	7.5	3.75	9	4.5	12	6	3	1.5
Suckler cows	6	4	7.5	5	9	6	12	8	3	2
Bulls < 15 months old	30	30	37.5	37.5	45	45	60	60	15	15
Bulls > 15 months old	30	30	37.5	37.5	45	45	60	60	15	15
Sows	5	5	6.25	6.25	7.5	7.5	10	10	2.5	2.5
Laying hens	9	6	11.25	7.5	13.5	9	18	12	4.5	3
Parent poultry	20	16	25	20	30	24	40	32	10	8

capacity of the slaughterhouses. Unprofitable beef production, together with the fact that support can only be paid on the basis of the number of animals on certain age, has triggered many farmers to take bulls to slaughterhouses at the same time. The capacity limits clearly restricted beef production in 1999, for example, and some of the animals that farmers were willing to take to slaughter houses in 1999 were not slaughtered until January-February 2000 (Maaseudun Tulevaisuus February 19 2000, p. 6). The seasonal excess supply of slaughter animals, however, does not affect the beef prices very much. In 1999 the beef price decreased only by 3.5% despite the seasonal excess supply in the latter half of the year (Lihatalous 2/2000, p. 44). Unresponsive beef prices are partly due to the intervention system and the fact that beef supply is smaller than beef consumption in Finland. Consumer preferences and strong demand for domestic

Table 8.10. The maximum rates of annual change imposed on the decision variables representing the use of feedstuffs (%).

	Base	Sensitivity 1	Sensitivity 2	Sensitivity 3	Sensitivity 4
Dairy cows	5	6.25	7.5	10	2.5
Suckler cows	5	6.25	7.5	10	2.5
Heifers	5	6.25	7.5	10	2.5
Heifers to be slaughtered	8	10	12	16	4
Bulls	8	10	12	16	4
Sows	10	12.5	15	20	5
Laying hens	10	12.5	15	20	5
Broilers	10	12.5	15	20	5
Parent poultry	10	12.5	15	20	5

beef do not allow very low producer prices of the domestic beef. However, Finnish beef prices have been lower than the EU average price level. To conclude, there are sound reasons to restrict the supply of slaughter animals by imposing lower bounds for the number of animals.

It is also assumed that all farmers do not switch instantaneously and fully between the bulls of different slaughter weight. Bulls (from dairy cows) older than 15 months have a slaughter weight of 290 kilos and the bulls less than 15 months old have a slaughter weight of 220 kilos in the model. The bulls with the higher slaughter weight also need more feed and cause more costs on farmers than the bulls with the lower slaughter weight. The upper and lower bounds (which are 30% annually in the base model) imposed on the number of both types of bulls reflect risk averse behaviour of farmers, as well as the fact that the costs of beef production vary between the farms. This means that all farmers do not make identical decisions when choosing the optimal slaughter weight. Hence, no immediate extreme shifts can be expected in the slaughter weights.

Having only two kinds of bulls of different slaughter weights in the model is a rough approximation of the production function of beef, as there could be more than two types of bulls with different slaughter weights and costs. However, only the total number of slaughtered animals and the average slaughter weight can be found in the public slaughter statistics. There is no statistical data on the distribution of the slaughter weight of the slaughtered animals and hence there is no statistical basis for the inclusion of several slaughter weight classes of bulls into the model. Having only two different slaughter weights for bulls the actual average slaughter weight can be always replicated by a unique combination of the two slaughter weight classes.

The use of each feedstuff is restricted from the previous year because of fixed factors embodied in the production systems. There are also biological reasons which restrict annual changes in the use of feed. Bovine animals, in particular, always need some minimum amount of roughage in their feed. Rapid changes in the feeding of bovines are not feasible, especially in the case of dairy cows and heifers.

9. Application 1: Agricultural policy analysis and exogenous technical change

This chapter presents an example illustrating the most central application of the DREMFIA model, the agricultural policy analysis. The base model was run for both base and Agenda 2000 policy scenarios (presented in Chapter 8) while keeping all – except the policy parameters – constant. The resulting development paths of production and agricultural income are presented in graphs labelled as “Base scenario” and “Agenda 2000”. Base scenario means that the policy of 1999 were to be continued until 2010. Agenda 2000 is the actual policy implemented in 2000-2006. Some details of Agenda 2000 are to be reviewed and possibly changed by the EU ministers of agriculture already in 2002. The national aids for animal husbandry in Southern Finland after 2003 are to be negotiated in 2003. In this study, however, medium and long-term impacts of Agenda 2000 are evaluated, and Agenda 2000 is assumed as was agreed by the EU ministers of agriculture in March 1999 (European Commission 1999b). It is assumed that there will be no changes in the agricultural policy after 2007, even if there will certainly be some changes. The national aids to be paid for animal husbandry in Southern Finland are also assumed to stay at the level of 2003 until 2010. Such assumptions are by no means realistic, but they are necessary in order to analyse medium and long-term effects of Agenda 2000 on Finnish agriculture. It is very difficult to forecast the changes in policy after 2003 or 2006. The results to be presented here, already presented in Ala-Mantila et al. (2000) up to the year 2006, show the way the DREMFIA model can be used in policy analysis.

A sensitivity analysis is performed by varying the flexibility constraints, thus investigating the importance of the constraints on the model outcome and policy conclusions. Even if one may validate the flexibility constraints using empirical data and different stylised facts of each production line, there is still some uncertainty concerning the values of the flexibility constraints. An explicit sensitivity analysis is performed rather than estimating the flexibility constraints from the data. The empirically estimated values of the flexibility constraints would be somewhat uncertain as well. The estimation of the flexibility constraints based on historical data could be deceptive because of the revolutionary change in Finnish agriculture due to the EU membership.

The upper and lower bounds of the production variables represent the extent of optimisation behaviour. Thus the flexibility constraints can be interpreted as technical, biological and behavioural constraints affecting the farmers’ optimisation behaviour. It is interesting to see how the variation in the flexibility constraints affects the model outcome, i.e. one may analyse the sensitivity of the results to the extent of optimising behaviour of farmers. As presented in Chapter 8.7 there are four sensitivity scenarios with different values given for the flexibility constraints. Since the Agenda 2000 scenario represent the likely agricultural policy until 2006, the sensitivity scenarios are run only for the Agenda 2000 scenario.

It turns out that the policy impacts, in most cases, are quite robust even if considerable changes are made in the flexibility constraints. This challenges the view that the outcome of RP models are totally determined by "arbitrary" flexibility constraints and thus the RP approach can provide no information on the policy impacts. At the same time, the view of agricultural adjustment as a dis-equilibrium process turns out to be indispensable if the results are to be close to the reality and of practical relevance to policy-makers.

9.1. On the use of a dynamic dis-equilibrium model in scenario analysis

Because of the many assumptions and exogenously given variables the DREMFIA model is not intended to produce exact forecasts of the future. The model should primarily be used in comparing between different development paths, rather than in predicting a single path. An analysis made by means of the presented dynamic model is based on comparisons between the results of the so-called base scenario (or "business as usual" -scenario) and alternative scenarios. The model yields a series of short-term disequilibria. Thus one needs to compare the whole development path of the base scenario with the development path of some alternative scenario. This kind of analysis is not based on comparative statics, but on a kind of "comparative dynamics". The series of short-term disequilibria may or may not converge to an equilibrium or to a stable development path. Policy measures or other changes may cause different dynamic patterns in production and its allocation between products and regions. There may be different turning points in the development paths in different policy scenarios. The development paths represent the whole adjustment process of the agricultural sector to a given policy change.

9.1.1. Problems of applying moving equilibrium formulation

As already noted in Chapter 6.10, the model can be solved as a "moving equilibrium" model by relaxing the flexibility constraints (i.e. the "relaxed model") in such a way that the allowable range of change is 50% for the variables representing number of animals, hectares of crops and feeding. The relaxed model describes a hypothetical situation where farmers are able to immediately choose the optimal, or at least close to the optimal, use of inputs. Such an experiment, however, turns out to yield results which are in clear contradiction to the observed reality. The actual ex post production data cannot be even roughly replicated by the model when relaxing the flexibility constraints.

The feeding variables change dramatically, in many cases close to 50% immediately in 1995 when relaxing the flexibility constraints and solving the model. In reality, however, the feeding of dairy cows, for example, changed by only few percentage units from 1994 to 1996 even if prices and support of grains changed dramatically in 1995 in the direction that favours the use of grain in feeding (MKL 1997, p. 35-37). Thus one would expect the use of grass in feeding to decrease and the use of grains in feeding to increase. This indeed happens in the model solution, and if there were no roughage constraints little or no grass or hay would be used in feeding. In other words, the use of roughage decreases by 50% and the roughage constraints become binding in the relaxed model.

The cultivated area decreases to 1.55-1.6 million hectares in 1995-1999 in the solution of the "relaxed" model, while the actual level of the cultivated area has been close to 2 million hectares in recent years. Pork production decreases to less than 160 million kilos in the model solution in 1995-1999, while the actual production level was more than 180 million kilos in 1999. The production of poultry meat is less than 52 million kilos in 1999 in the outcome of the relaxed model, while the actual production volume was 25% higher (65 million kilos in 1999). Milk production, however, is only slightly smaller in the solution of the relaxed model than the actual production since the sudden large changes in feeding make the production profitable in the relaxed model. In reality, however, the feeding of animals has changed only little and the profitability of dairy production has decreased. At the same time, the production volumes of milk have increased. Despite the strong incentives for changes, fixed production factors and animal biology have prevented immediate changes in feeding.

Hence, one can conclude that the years 1995-1999 do not represent an economic equilibrium and the moving equilibrium scheme is problematic. One needs a model which allows the analysis of the adjustment to changing policy as a dis-equilibrium process where the adjustment of feeding and fixed production factors is gradual, not instantaneous. The DREMFIA model outlined in Chapter 6 is one such model.

9.1.2. Calibrating the model to ex post data

The model outcome of the base scenario must be in accordance with the known production activity levels, production costs, and incomes of the ex post years, i.e. 1995-1999. If the model outcome is very different than the ex post data the model is too abstract from reality and policy analysis conducted using such a model is unlikely to be of relevance to policy makers and other interest groups in agriculture.

In DREMFIA model the flexibility constraints ensure that production activity levels are close to the actual ones during the first 1-2 years of the simulation. In later years, however, the model outcome may be very different to the actual. Some calibration is done in order to replicate the actual development until 1999. Sunk costs are adjusted to calibrate the production variables, as described in Chapter 8.6. In addition to the sunk costs, also the substitution elasticities between imported and domestic products, as well as the processing margins of dairy products and the slopes of the export cost functions, are adjusted in order to calibrate the imports and exports. There is little empirical data that can be used in estimation of these parameters. The processing margins of dairy products, for example, are proprietary information of dairy processing companies. Hence, these parameters with little empirical basis are used to validate the model, i.e. to calibrate the production variables close to the ex post data. The parameter values used are presented in Chapter 8. Extensive statistical data material from various are used in determining other parameters, like the use of inputs, and such parameters are not used in the model calibration.

Exact calibration was not always possible, however, using the calibration parameters. Adjusting individual single parameter values, like substitution elasticities or slopes of export cost functions, one cannot calibrate the model exactly at all the ex post years. Single parameter values that calibrate production and foreign trade variables to ex post data at one year may not calibrate the model as well at other years during the ex post period. This is partly because of various random factors, like weather conditions, market disturbances, BSE scandal, etc. that influence the actual production quantities and foreign trade. Also product prices (of pork, for example) may fluctuate considerably during a year. A model that is solved for each year separately using annual average prices may not be always calibrated exactly to ex post data. However, if the model were calibrated exactly to the *ex post* data all random factors would be included in the parameter values used in the calibration, and the model would not be consistent in later years. The model was calibrated in order to replicate the actual production levels of the year 1999 as closely as possible since 1999 is the starting year when analysing the effects of Agenda 2000. Consequently, the production variables were calibrated very close to the actual 1999 levels, but there are small differences between the model outcome and the ex post data during 1995-1998.

The difference between the actual data and the simulation results in the ex-post period 1995-1999 is relatively small, however, (in most cases less than 1%) and that does not make the model too abstract from the reality in order to conduct policy analysis. Activity levels, as the number of hectares of crops and the number of animals, are calibrated very close to the actual ex post data but the crop yield levels, since they are random variables, are not calibrated. It is assumed in the model that farmers expect average yields. This means that production quantities in the ex post period may not equal the actual ones. One should also note that the model was calibrated to ex-post data of 1995-1999 since the data of the year 2000 was not yet available during this study was written.

The model outcome in the later *ex ante* years of the base scenario are dependent on the exogenous variables in the model, i.e. the inflation rate, as well as the scenario parameters concerning productivity and production efficiency.

9.2. Crop production and land use

The model includes the main arable crops cultivated in Finland, as well as main livestock production lines. Thus the model includes the so-called basic agriculture, and horticulture and sheep and horse husbandry are excluded. The exclusion of some crops and animals of minor importance results in a total crop area which is slightly lower than the actual one. The total crop area (excluding set aside) simulated by the model is presented in Figure 9.1.a. The calibration to the actual data is not exact partly because of random effects, like the varying weather conditions during the sowing period which greatly influences the land use. However, the difference between the ex post data and the simulated is less than 2%.

One can see that the *Agenda 2000* scenario results in slightly higher crop areas than the continuation of the 1999 policy, termed as *base* scenario. This is due to the lower product prices and higher per hectare payments in the Agenda 2000 which results in more extensive production. There is also additional support for drying grain in the Agenda 2000, which partly results in higher cereals areas, in particular.

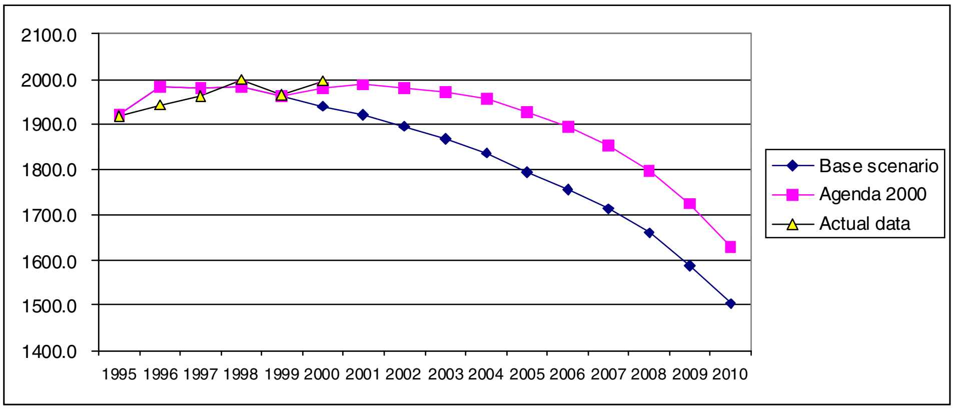

Figure 9.1.a. Total crop area (excl. Set-aside) (1000 ha).

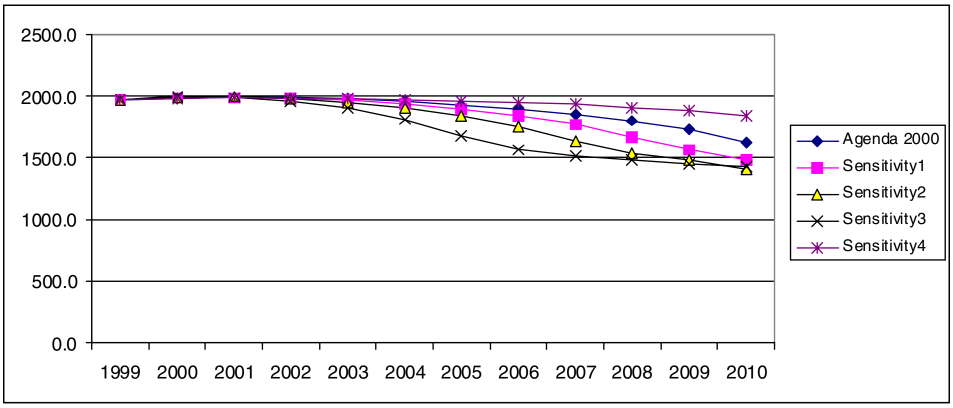

Figure 9.1.b. Sensitivity of the total crop area to the flexibility constraints in the Agenda 2000 scenario.

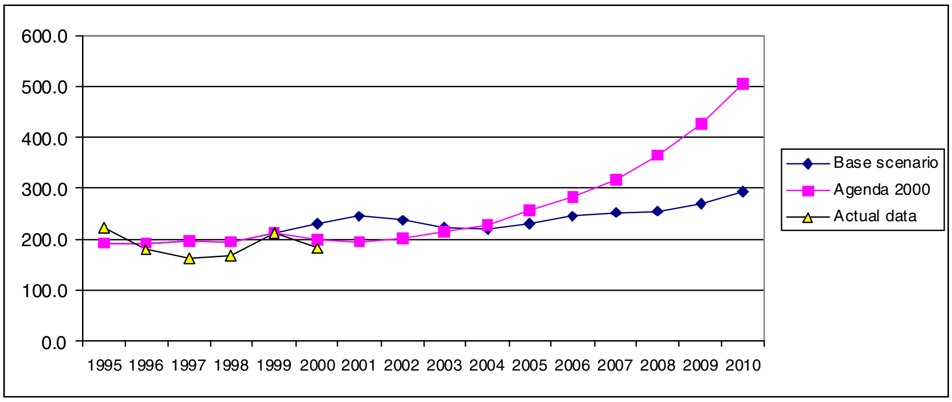

Figure 9.2.a. Total set-aside area (both ordinary and green set-aside) (1000 ha).

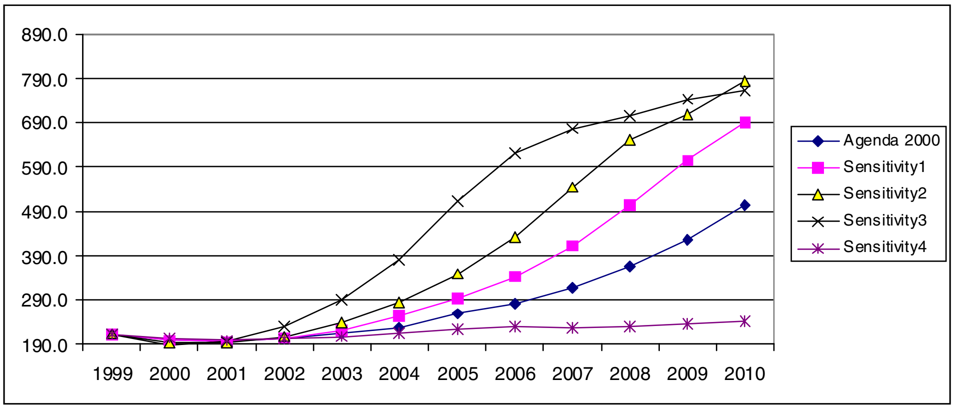

Figure 9.2.b. Sensitivity of the total set-aside area to the flexibility constraints in the Agenda 2000 scenario.

The total crop areas are sensitive to the flexibility constraints (Figure 9.1.b). The flexibility constraints influence only slightly the land allocation between different crops. However, the flexibility constraints have a substantial impact on set-aside (Figure 9.2.b). If a wide allowable range of change is given for the set-aside, it tends to increase relatively rapidly in the model. In the Agenda 2000 scenario the rate of change is restricted to, 20% and 30% for green set-aside and ordinary set-aside per year, respectively, which results in quite modest increase in the area under set-aside. When increasing the rate of change up to 40% and 60% per year (Sensitivity scenario 3) the set-aside increases very rapidly up to 790,000 hectares until 2010 thus replacing the area under cultivated crops. If the rate of change of the ordinary set-aside and green set-aside is restricted to 15% and 10% per year (Sensitivity scenario 4) the total set-aside increases hardly at all. Given the small variations in the set-aside area during the recent years great annual changes can be seen unrealistic. Thus the rates of change given in the Agenda 2000 scenario are close to the actual ones and the outcome of the Agenda 2000 scenario can be seen as more realistic than the outcome of the sensitivity scenarios 1-3.

The model slightly overestimates the set-aside area in the ex post period. The difference between the actual data and simulated is 22%, at greatest. The simulated set-aside area at 1999, however, is very close to the actual.

The very small rate of change of the set-aside area assumed in sensitivity scenario 4 may underestimate the rationality and optimising behaviour of the farmers. If only small changes in the area under set-aside are allowed more land will become unused, i.e. not cultivated and not included in the set-aside area. In the model there are no other alternative land uses to crop cultivation and set-aside, except for idling the land (Figure 9.3.a-b), which causes no costs and no revenues in the model. It is understandable, however, that the lack of alternative uses of land leads to sensitivity of set-aside area to the flexibility constraints. There are no direct non-linear relationships in the model influencing the use of set-aside. This means that the use of set-aside is likely to be subject to abrupt changes typical for linear programming models. Changes in the costs of set-aside may greatly influence the area under set-aside in the long term. The maximum annual rate of change imposed on the set-aside area influences the total cultivated area and the cereals area as well.

The decrease in the cultivated area in both scenarios, and in the base scenario, in particular, is a result of the decrease in both cereal and grass areas. The given increase in productivity and production efficiency are not enough to compensate for the given rate of inflation of input prices. Thus the set-aside area gradually increases. The areas of feed crops, however, are relatively less sensitive to the flexibility constraints and the costs of set-aside, however, since the number and feed use of animals influences feed production. The increase of yields of dairy cows, sows and hens result in an increase in feed use efficiency,

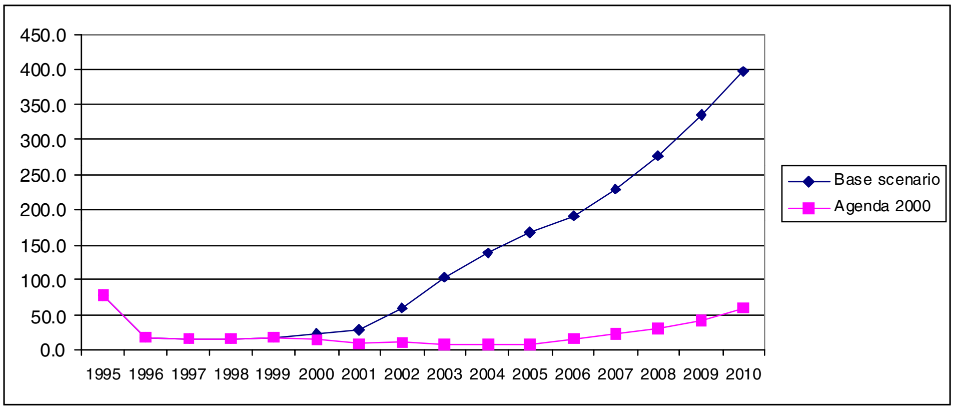

Figure 9.3.a. Idled land (1000 ha). No actual data available[4]*.*

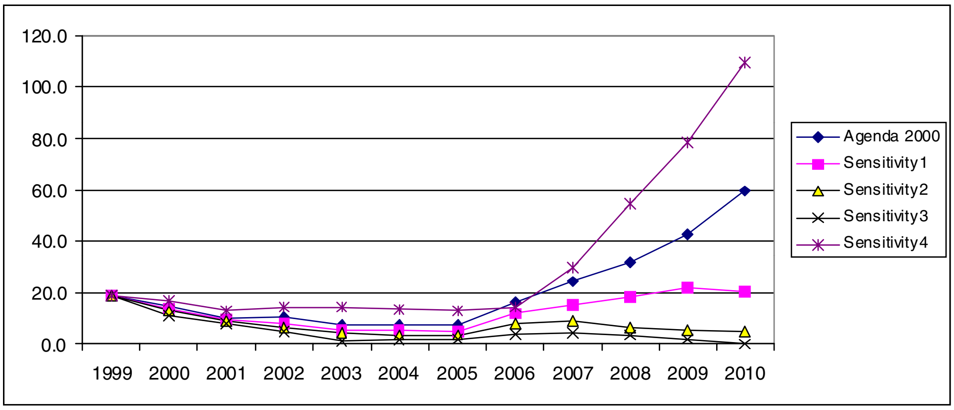

Figure 9.3.b. Sensitivity of the idled land to the flexibility constraints in the Agenda 2000 scenario.

which diminishes the amount of feedstuffs needed per kilo of output. This decreases the feed crop areas in the long term. The grass and cereal areas also depend on the given rates of change imposed on the feeding variables which determine how fast the feeding of animals may change.

In the ex post period the simulated grain area is slightly higher than the actual cereals area. This is partly due to difficult weather conditions in sowing period of bread grain. It is also possible that farmers do not shift as consistently from grass to cereals as the model simulation would suggest (Figures 9.4.a and 9.5.a). This may be due to risk averse behaviour of farmers or soil qualities which may not favour the shift from grass to grain. The grain areas, however,

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[4] No idled land can be found in official statistics of the use of agricultural land

have increased in Finland significantly, up to 20%, since 1995. The difference between the actual data and simulated time series is relatively small.

The cereal area seems to increase in the first years of the Agenda 2000 scenario while remaining rather stable in the base scenario. In 2006 there are 100,000 hectares more under grain in the Agenda 2000 scenario than in the base scenario. In 2010 the difference is 70,000 hectares. In the Agenda 2000 scenario the decreasing product prices and increasing per hectare payments increase the area under cereals while the production quantities change only little. This is due to decreasing fertilisation and yield levels. At the same time the total grass area decreases constantly in both base and Agenda 2000 scenarios. It is profitable to increase the use of grain in the feeding of cattle in both policy scenarios. The grain area is sensitive to the flexibility constraints in the long term since it

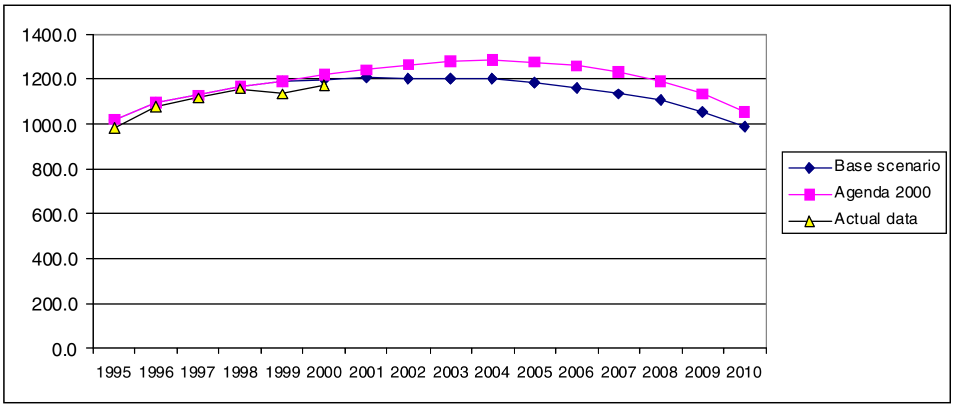

Figure 9.4.a. Total cereals area (1000 ha).

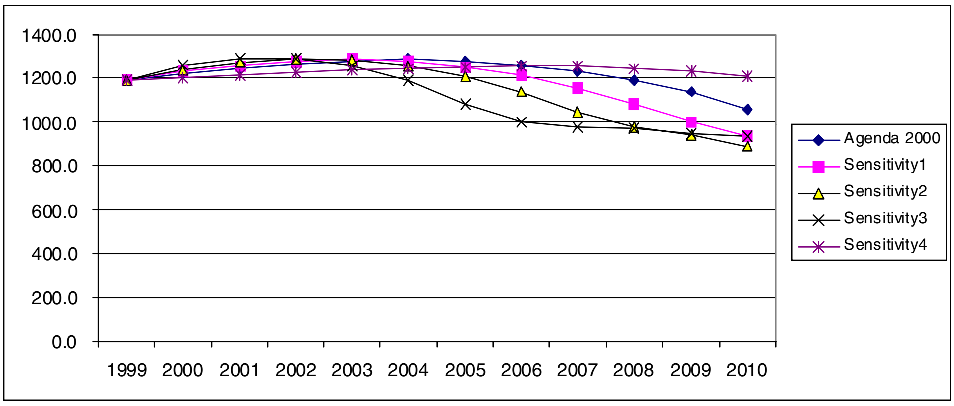

Figure 9.4.b. Sensitivity of the cereals area to the flexibility constraints in the Agenda 2000 scenario.

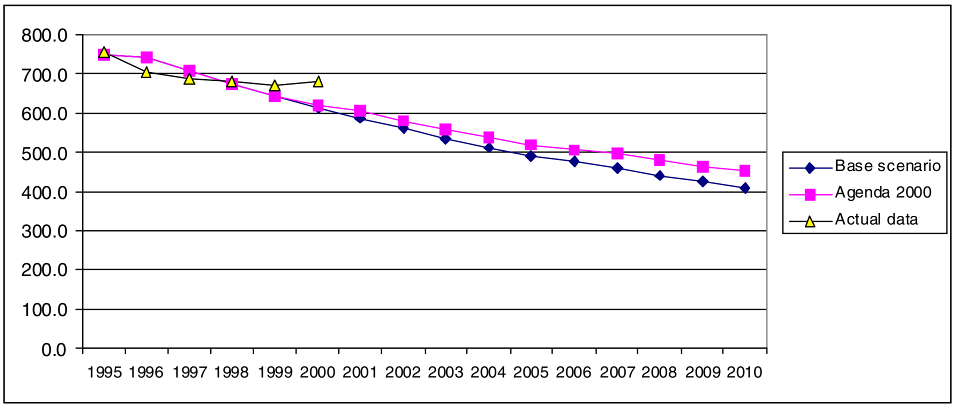

Figure 9.5.a. Total grass area (excl. Fallow land) (1000 ha).

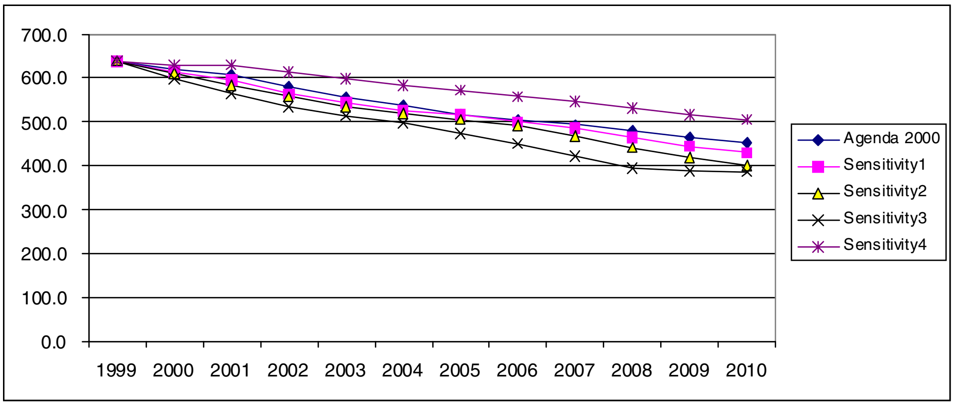

Figure 9.5.b. Sensitivity of the grass area to the flexibility constraints in the Agenda 2000 scenario.

depends on the flexibility constraints how rapidly grain is substituted for grass in the feeding of animals. The grain areas are influenced by the flexibility constraints imposed on set-aside.

The grass areas decrease constantly in all policy and sensitivity scenarios. The grass areas are somewhat dependent on the flexibility constraints, but relatively less than the grain areas. The grass areas in the Agenda 2000 scenarios are influenced by the decreased grain prices, increased area payments, and increased cereal areas. Less fertiliser is applied per grass hectare in the Agenda 2000 scenario than in the base scenario, which results in slightly lower grass yields and larger grass areas. The fertilisation has more effect on the grass yields than on the cereal yields. The area under grass in 2006 is 30,000 hectares and in 2010 44,000 hectares larger than in the Agenda 2000 scenario than in the base scenario.

The total area under crops and set-aside is 240,000 hectares larger in the Agenda 2000 scenario than in the base scenario in 2010. Agenda 2000 results in greater arable land area in active use as well as in a slighly larger number of farms if the same production efficiency development and average farm size growth is assumed in both scenarios.

9.3. Milk production

There are 18 different dairy products in the model which are priced at the retail price level. Fixed processing costs are assumed, i.e. the dairy processing industry is able to compensate for the inflation in the prices of inputs (other than raw milk). The milk production volumes thus depend on the costs of milk production at the farm level as well as at the processing industry. The average product prices in the EU are kept fixed except in the case of Agenda 2000 dairy reform in 2005-2007, which decreases the prices of butter, milk powder and raw milk by 15%.

In the ex post period, the simulated milk production volumes are slightly higher (by 0.8%-3.5%) than the actual. This is because the exports and imports of different dairy products cannot be replicated exactly by adjusting the substitution elasticities of the imports and domestic production, and the slopes of the export cost functions. At 1999, however, the level of imports and exports were quite closely replicated by the model. Hence the 1999 production volume is very close to the actual one.

There are some tendencies in the consumption of dairy products, like decreasing butter and liquid milk consumption and increasing cheese and yoghurt consumption, which are taken into account. The decrease in the consumption of liquid milk in 1990-1999 (MTTL 2000, p. 43) make it easier for the imports to substitute for domestic production. Liquid milk and other fresh milk products cannot be stored and they are expensive to transport abroad.

The milk production volumes are constantly close to the quota limits in the base scenario. In the Agenda 2000 scenario the decreasing national support in Southern Finland in 2000-2003 leads to decreasing milk production, while the production volumes remain close to the quota limits in the other parts of the country. In 2010 the total milk production is 5% less in the Agenda 2000 scenario than in the base scenario where all prices, production quotas and support remain at the 1999 levels. Milk production decreases until 2003. It is assumed that after 2003 there are no more reductions in the support of milk production in Southern Finland. The increasing productivity and production efficiency results in a temporary increase in milk production in Southern Finland in 2004. The dairy reform of the EU, however, starts in 2005. The producer price of milk is reduced by 15% in three steps until 2008, which is partly compensated for by direct subsidies paid per animal. This results in further

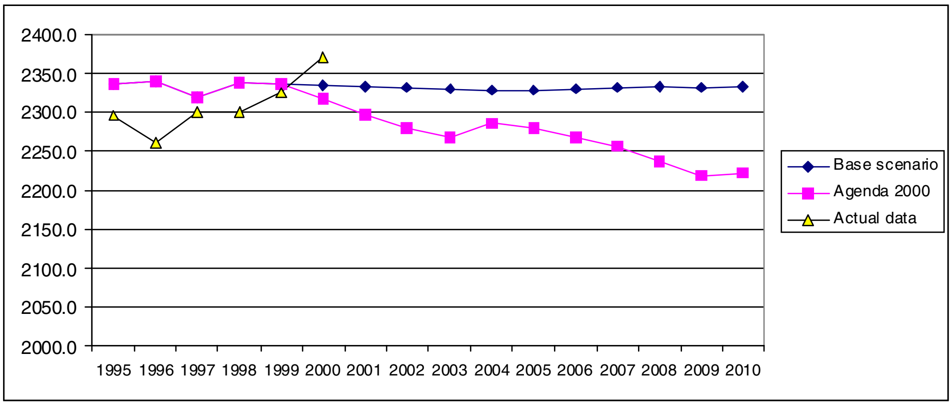

Figure 9.6.a. Milk production volume (mill. kg).

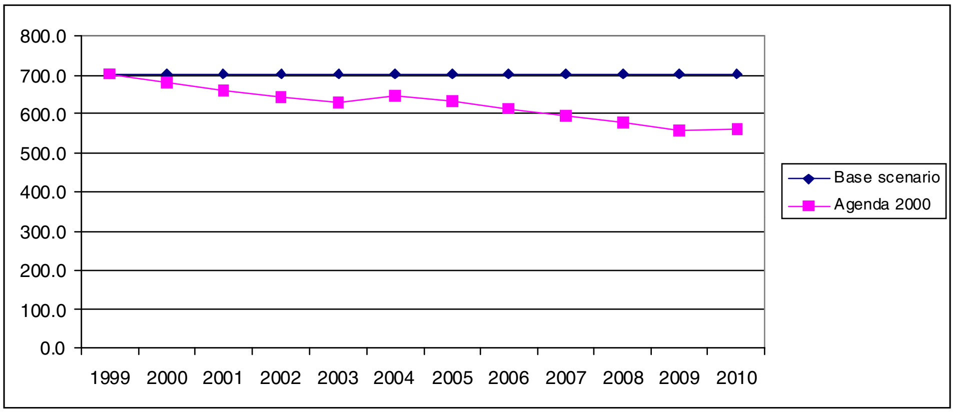

Figure 9.6.b. Milk production volume in Southern Finland (mill. kg). No actual data available due to differences in regional aggregation.

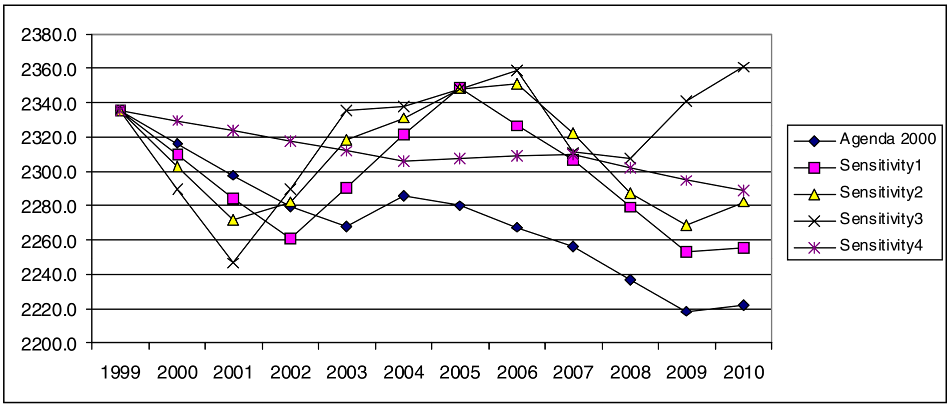

Figure 9.6.c. Sensitivity of the total milk production volume (mill. kg) on the flexibility constraints.

decrease in the profitability of milk production. The decreased national support has already resulted in lower profitability in Southern Finland compared to the other parts of the country. Thus the milk production decreases further in Southern Finland after 2004, while the productivity and efficiency development (which is the same in all regions, in relative terms) is enough to compensate for the inflation of inputs and the decreasing profitability due to the Agenda 2000 dairy reform in the other parts of the country.

Milk production stabilises by 2010 to 2,220 million kilos in total, and to 560 million kilos in Southern Finland. The increased production efficiency, productivity and the change in the feed use of animals will eventually stop decreasing trend of milk production in Southern Finland. This stabilisation effect is also partly influenced by the stabilised imports and exports of milk products: given certain substitution elasticities and export cost functions, the exports and imports of different dairy products gradually converge to relatively stable levels. Less competitive domestic dairy products become replaced by imports, while exports of some dairy products increase. Since different amounts of milk fat and skimmed milk are needed in the processing of dairy products, there is a very limited number of economically viable alternatives of exports. The exports of yoghurt and emmental cheese are relatively stable, while the exports of butter and milk powder are constantly decreasing in both policy scenarios. Exports of other cheeses (comprising cheeses other than Emmental and Edam) gradually increase in the model outcomes. Imports of Edam increase constantly and gradually replace domestic production. Imports of yoghurt and Emmental cheese and other cheeses (except Edam and Emmental) decrease slightly.

Thus both the exports and imports converge to relatively stable levels, or at least to constant upward or downward trends. The overall effect of the export and import patterns is the convergence of milk production close to some “equilibrium level” in 2010 when all fixed costs are taken into account in the production.

As presented in Figures 9.6.c, the total milk production volume is to some extent sensitive for the given maximum rates of change in the number of animals and feeding coefficients. The difference in milk production volume between Agenda 2000 and Sensitivity scenario 3 is less than 6% in 2010, however. The changes in feeding coefficients, in particular, affect the production costs and thus the profitability and volume of the production. Greater annual changes thus imply more rapid decrease in the milk production volumes in the short term. In the medium and long term, however, more economic feeding in the sensitivity scenarios 1-3 results in greater milk production volumes. In sensitivity scenario 3, where the maximum annual rates of changes were doubled from those in the Agenda 2000 scenario, the milk production volume almost reaches the quota limits increased by 1.5% in the Agenda 2000 reform. Similarly, the reduced annual changes in sensitivity scenario 4 (where the maximum rates of annual change were reduced by 50% from those in Agenda 2000) result in lower profitability of the production and continually decreasing production in Southern Finland. The production volume in sensitivity scenario 4 decreases very slowly despite the lower profitability. This is because the annual decrease in the number of animals is restricted to 3%. Such a small rate of decrease is almost compensated for by the given exogenous annual increase in the yield potential of dairy cows and by the increase of milk yields due to changes in feeding. Hence, the milk production volume does not respond to reduced profitability due to the flexibility constraints concerning the number of animals. Consequently, the very low rates of maximum annual change of the production variables given in sensitivity scenario 4 obscure economic logic and they should be avoided when using the model.

The feeding of dairy cows changes consistently in the direction of more grain feeds in both policy scenarios. In Southern Finland and in Ostrobothnia the amount of grain-based feedstuffs increases up to 50% by 2006 and up to 55-60% by 2010. In Central Finland the share of grain-based feed-stuffs increases to 45-50% until 2006 and to 50-55% until 2010. In northern Finland the share of grain-based feedstuffs increases only slightly since the share of grain based feed stuffs is already quite high in the north. The reduction of milk prices in 2005-2008 reduces incentives for higher milk yields per dairy cow and makes the use of protein feeds as well as some industrially processed grain-based feedstuffs less profitable. However, the effect of the reduced prices on the milk yield per dairy cow is only 1-1.5 % lower in the Agenda 2000 scenario than in the base scenario until 2006. This is because the increase in the milk yields of dairy cows is partly exogenous (an annual increment is assumed in the scalar parameter of the milk yield function) and independent of the economic conditions, and partly because of the fact that grain-based feedstuffs become more popular in both scenarios thus resulting in almost identical milk yields.

In reality, the change in the feeding of dairy cows has been relatively slow, and actually slower than in the Agenda 2000 scenario and in the sensitivity scenarios 1-3 (MKL 2000). Thus the sensitivity scenarios 1-3 are overly optimistic when assuming relatively rapid changes in the feeding of animals. Some change, however, has taken place in the feeding of animals, and more grain is used in the feeding of cattle than before the EU membership (KM 5/2000, p. 10).

9.4. Beef production

The model slightly under-predicts (by 0.7-6%) beef production in 1995-1997. This is due to the fact that the actual slaughter weights have not decreased as much as the model suggests. Flexibility constraints prevent rapid changes in slaughter weight in the model (i.e. a shift from heavy bulls to younger lighter bulls). Decreased beef prices should result in decreased slaughter weights, at least in long term, because production costs have decreased far less than the price of beef in recent years.

In the base scenario beef production decreases to 76 million kilos by 2010, whereas in the Agenda 2000 scenario beef production decreases down to 71 million kilos from 89 million kilos in 2000 (Figure 9.7.a). This is due to the decrease of beef prices by 20% due to Agenda 2000 and the resulting reduction in the carcass weights of dairy bulls. In the base scenario the carcass weights of dairy bulls decrease in Central and Northern Finland, while there is no change in carcass weights in Southern Finland and in Ostrobothnia. In the Agenda 2000 scenario the average carcass weights decrease by 5-15% in all regions. The decreasing grain prices by 15% and the change of feeding to more grain-based feeding is not enough to make beef production profitable.

Beef consumption is assumed to follow recent trends and decrease to 82 million kilos until 2010. Hence the imports of beef will amount to 6 million kilos in the base scenario and to 11 million kilos in the Agenda 2000 scenario by 2010. Exports of beef are clearly unprofitable and are decreased to less than 1 million kilo by 2004 and to zero by 2005.

The beef production volumes from specialised beef farms (with beef breeding animals) are higher in the Agenda 2000 scenario than in the base scenario. This is due to the extensive production practices of specialised beef farms which utilise pasture roughage in feeding at low costs (in Finland, however, pasture grass is, available only in summer). Despite the reduced beef prices the increased per hectare payments and increased beef premia paid per animal result in 29,000 suckler cows in 2010, which is 10,000 suckler cows more than in the base scenario. It was assumed in the model that beef from breeding cattle is paid price a premium of FIM 5/kg on the markets because of significantly better beef

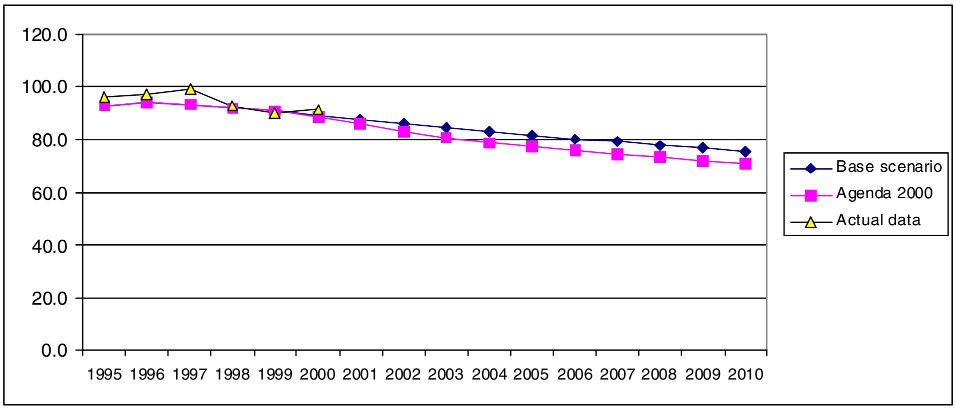

Figure 9.7.a. Volume of beef production (mill. kg).

quality compared to the beef from the dairy cattle. The costs per bull in the specialised beef farms was estimated to be 40% lower than on dairy farms. The efficiency in feed use (measured as fodder units needed per one kilo of meat) is higher on specialised beef farms than on dairy farms.

The feeding of bulls and beef cattle changed to the direction of more grain based feed stuffs equally in both scenarios. The share of grain based feed stuffs increased up to 50% in Central and Northern Finland, and to 60% in Southern Finland and in Ostrobothnia by 2010.

The flexibility constraints have relatively little effect on beef production volumes. This means that beef production volumes are quite robust on the extent the farmers optimise (sensitivity scenarios 1-3 in Figure 9.7.b). If farmers are able to respond to the changes in policy more rapidly changes in the beef production will also be somewhat quicker. Despite this, beef production in 2010 is almost the same in different sensitivity scenarios. It must be noted that the milk production quantities and thus the numbers of dairy cows are somewhat different in the Agenda 2000 scenario and the sensitivity scenarios 1-3, and there is still very little variation in the beef production volumes in different sensitivity scenarios. The milk production volume and number of dairy cows is 6% larger in sensitivity scenario 3 than in the Agenda 2000 scenario in 2010, but the beef production volume is only 0.8% larger in sensitivity scenario 3. This is because the number of animals of different weights may change more in sensitivity scenario 3, especially in areas where beef production is unprofitable, compared to the Agenda 2000 scenario. The joint effect of wider ranges of the number of animals and feeding coefficients seems to cancel out each other in beef production, and the resulting beef production volume is quite robust on the flexibility constraints. The number of dairy cows decreases very slowly in sensitivity scenario 4 which implies that beef production volumes decrease at a slower rate than in other scenarios.

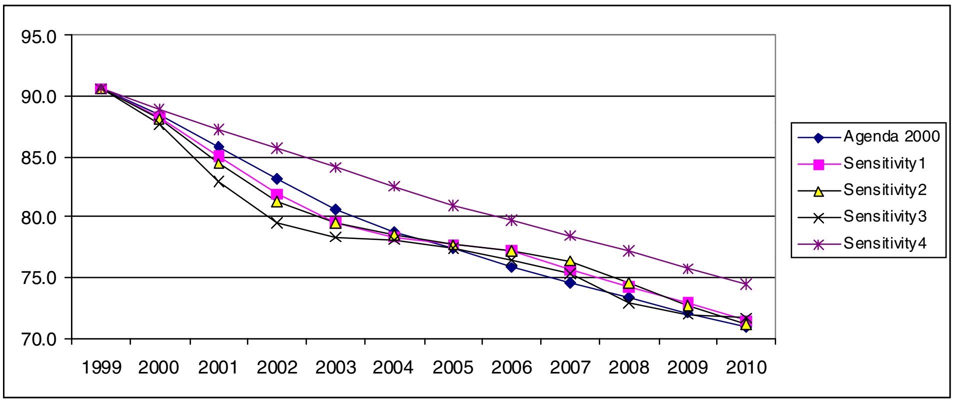

Figure 9.7.b. The effect of the flexibility constraints on beef production.

9.5. Pork production

The model slightly under-predicts (by 3.6%-4.8%) pork production in 1995-1998. This is because the investments at hog farms increased very rapidly in 1996-1997 and hence the production increased still in 1998 despite a decrease of pork prices. There were also large fluctuations in annual pork prices in the ex post period. The 1999 production level, however, is very closely replicated by the model. On the other hand, the model cannot fully replicate the decreasing pork production in 2000. The prices increased by 15% in 2000, on the average, but still the production decreased by 6% The rapid turns of pork production at 2000 could not be replicated using the model at any non-negative values of sunk costs.

Agenda 2000 policy reform does not influence pork prices directly. The changes in the prices of beef and grain have some effect on pork prices, however. Pork prices in the EU are assumed to decrease by 9% by 2001 in this study. Using this assumption in the model simulations, pork production decreases to 171-172 million kilos in both policy scenarios (Figure 9.8.a). Agenda 2000 seems to have little effect on pork production if prices decrease 9%. This is because the decreased grain and pork prices roughly cancel out each other. It can be easily verified using the model that a price reduction of 15% until the end of 2001 will result in a production volume of 157 million kilos by 2010. Thus the pork production volume is to some extent sensitive to the assumed EU price level in the future as well as to other assumptions concerning productivity and efficiency development.

During 2000-2004 there is more pork production in the Agenda 2000 scenario than in the base scenario. This is due to increased support for grain in Agenda 2000. The extension of the support for less favoured areas (LFA) to Southern Finland (support area A) benefits pork producers.

It turns out that the pork production volumes are quite robust on the optimising behaviour of farmers, i.e. flexibility constraints (Figure 9.8.b). The explanation of this result follows the same kind of reasoning as presented in the case of beef production: the extended maximum rates of change of feeding variables and the number of animals cancel out each other in a great extent. In the medium term the more efficient feeding will result in slightly higher production volumes. Later, when the optimal feed mix is found under certain energy and protein constraints, the number of animals adjust more flexibly to the “equilibrium path” in the sensitivity scenarios 1-3 than in the Agenda 2000 scenario. The overall result is that the pork production volume is quite insensitive to the flexibility constraints.

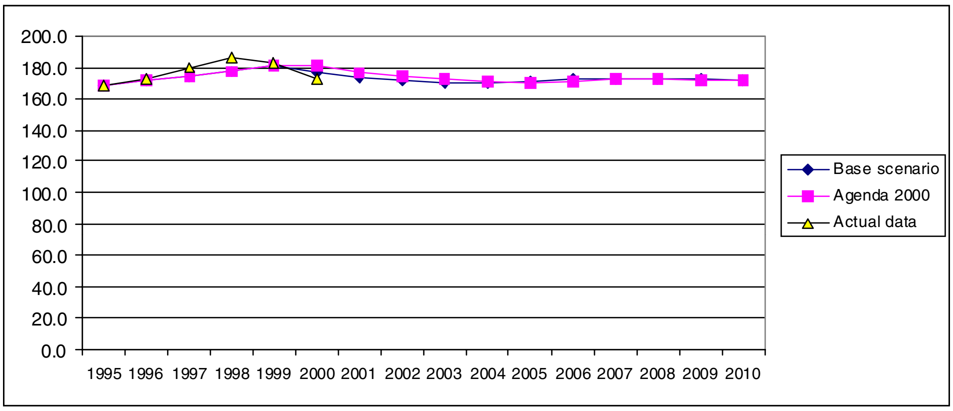

Figure 9.8.a. Volume of pork production (mill. kg).

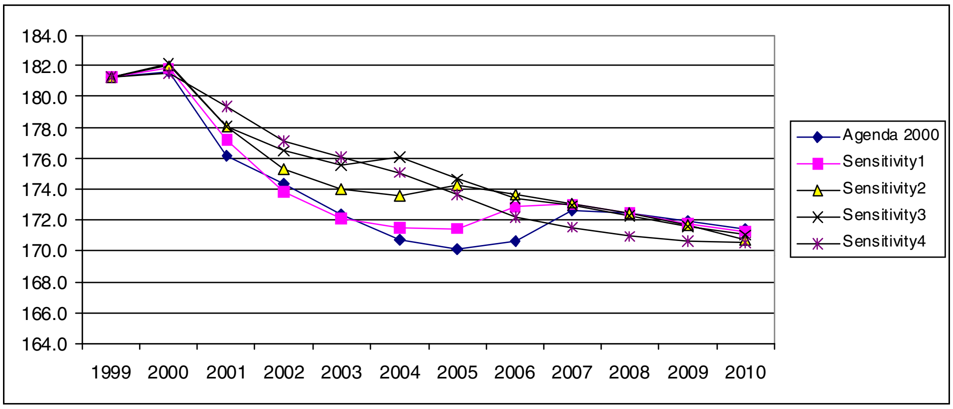

Figure 9.8.b. Sensitivity of pork production volume to the flexibility constraints.

9.6. Production of poultry meat

The EU market price of poultry meat is assumed to decrease by 9% (as is assumed for pork) because of the grain price reductions due to Agenda 2000. Considerable improvements are expected in the efficiency of poultry meat production due in investments to large production units as well as the exit of small producers. 455 poultry farms exited production 1999, when there were still 1,200 egg producing farms in Finland.

The consumption of poultry meat has increased at a very fast rate in the 1990s. The imports of poultry meat has increased only slightly, which means that the major part of the increased consumption has been covered by the domestic production. Large investments have been made in poultry meat production facilities and the efficiency of production has increased rapidly. Given a rapid efficiency development and sunk costs (one can motivate the high level of sunk cost by the increased investments) the model replicates very closely the increasing trend of production. There are little imports of poultry in the model (as well as in the reality) in the ex post period since the domestic production has been competitive and able to supply the increasing demand.

Assuming a rapid increase in the production efficiency of poultry meat production, as well as the continuation of a strong increasing trend in the consumption, the model outcome show that the Agenda 2000 policy may result in slightly lower production volumes until 2010 (Figure 9.9.a). This means that the price decrease of 9% according to Agenda 2000 cannot be totally compensated by reduced grain prices and increased support for grain. If the strong development in the production efficiency taken place in the recent years continues, the domestic production will to cover the major part of the increasing demand.

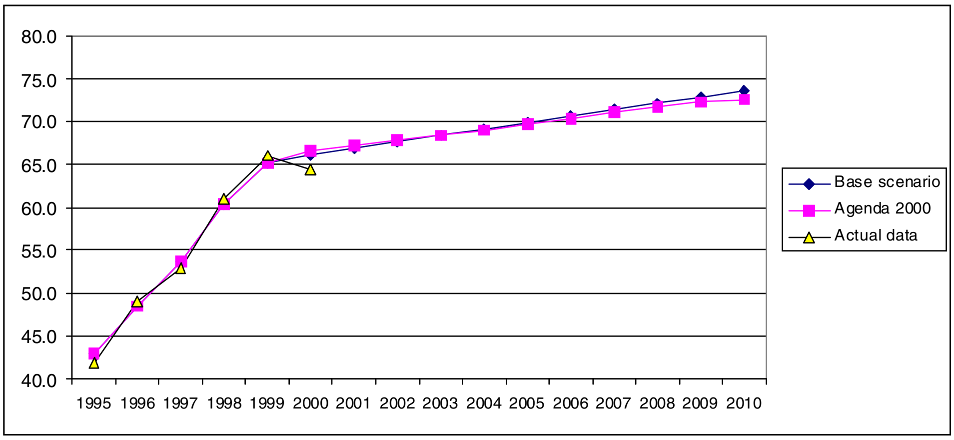

Figure 9.9.a. Production volume of poultry meat (mill. kg).

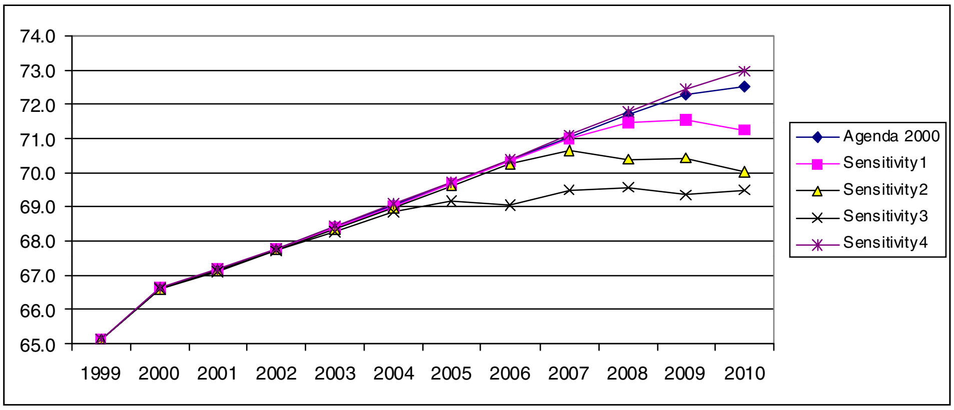

Figure 9.9.b. Sensitivity of poultry meat production to the flexibility constraints.

However, the poultry meat production volume is to some extent sensitive to the flexibility constraints (Figure 9.9.b). The production quantities are slightly lower in the sensitivity scenarios 1-3 than in the actual Agenda 2000 scenario. In the Agenda 2000 scenario the number of poultry animals may increase by 16% and decrease by 20% annually. Thus there is plenty of room for changes in poultry production in the scenarios. In the sensitivity scenarios 1-3 the maximum annual decrease in the number of animals is 25-40% and the maximum annual increase is 20-32%. The feeding variables are also given a relatively large possible range of change. One could imagine that faster change in feeding might result in better profitability and higher production volumes. However, there are less options and less variation in the feeding of poultry animals than in the case of cattle animals, for example, and the optimal feed mix can be achieved quite soon in the model. After the optimal feed mix is found the flexibility constraints affect only the number of animals.

The reason for lower poultry production quantities in the sensitivity scenarios 1-3 (with larger allowable range given for the production variables) is that poultry meat production tends to decrease in Ostrobothnia and in Central and Northern parts of Finland. There is relatively less poultry meat production in central and northern Finland since close to 90% of all poultry meat production is concentrated to southern Finland and almost 10% in Ostrobothnia. The rate of decrease of production in some areas is influenced by the flexibility constraints. However, despite the heavy investments and considerable improvements in production efficiency, the poultry meat production is not profitable enough in Southern Finland in order to increase production and to compensate for the reduced production in some other areas. Thus the wider range of maximum annual changes in the number of animals result in lower production quantities.

9.7. Agricultural income

Since the DREMFIA model includes only the most important production lines of Finnish agriculture and excludes horticulture, for example, the total agricultural income calculated on the basis of the model outcome is slightly lower than the actual total agricultural income. Furthermore, the supports are always accounted for the production variables in a logical way, and no delays in the payments of the support are taken into account. Thus the agricultural income of the model is not fully comparable to the actual agricultural income presented, for example, in MTTL 2000 (p. 87-89).

During 1995-1999 the agricultural income of basic agriculture, calculated using the production variables, prices and supports, is close to the actual agricultural income of basic agriculture (presented in MTTL 2000). This is because the production variables have been calibrated close to the actual ones and the endogenous prices in the model are also close to the actual ones. Income of year 2000 is not, however, replicated exactly by the model since the rapid increase of input prices of that year was not yet completely known when running the simulations.

In the base scenario the annual agricultural income is close to FIM 5.5 billion in 2000-2010 (Figure 9.10.a). Thus the productivity and production efficiency development compensates for the inflation of the prices of primary inputs in the base scenario. The Agenda 2000 scenario results in a significant improvement in the total agricultural income in Finland in 2000. This is due to the increased CAP support (MTTL 2000, p. 8), which compensate for the price reductions in the Agenda 2000 CAP reform, and due to the increased and LFA support.

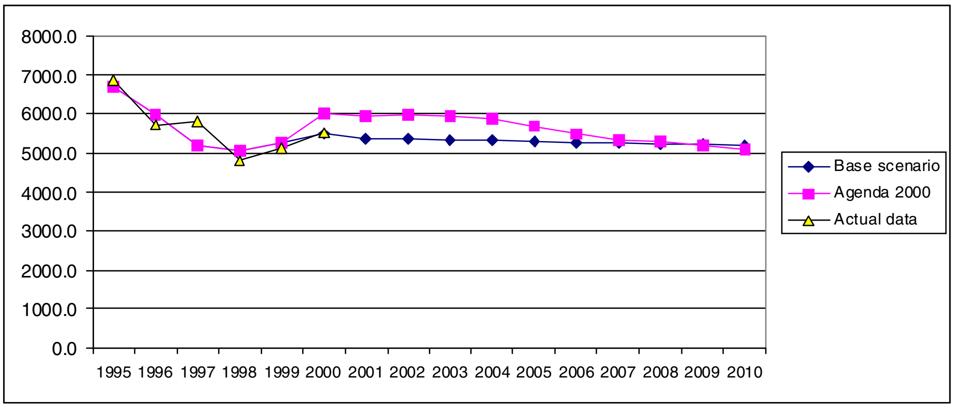

Figure 9.10.a. Total agricultural income of basic agriculture (FIM million).

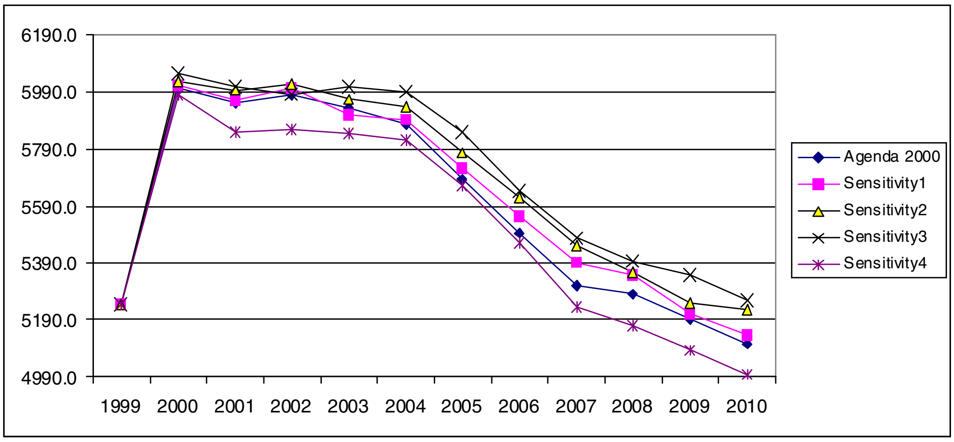

Figure 9.10.b. Sensitivity of the total agricultural income to the flexibility constraints.

It also turns out that the overall agricultural income in the Agenda 2000 policy is insensitive to the flexibility constraints, i.e. to the optimising behaviour of farmers (Figure 9.10.b). Increasing the allowable range of change of the production variables by 100% (in sensitivity scenario 3) increases the agricultural income by 3%, while decreasing the allowable range of change of the production variables by 50% decreases the agricultural income by 2% until 2010.

One should note that there is a positive change in the agricultural income in the base scenario in 2000 as well. This reflects the gradual and lagged adjustments of the production variables in the model due to the flexibility constraints. The policy parameters do not change in the base scenario after 1999, but it takes a couple of years before the production variables are fully adjusted to the 1999 policy. In the later years, the production efficiency and productivity development roughly compensate for the inflation of the input prices. Hence, there are no oscillations in the agricultural income after 2001 in the base scenario. There are more fluctuations in agricultural income in the Agenda 2000 scenario where the prices and support change constantly in 2000-2003 and 2005-2007. However, the optimising behaviour results in stable development paths in 2-3 years despite the flexibility constraints: the changes in agricultural income tend to smooth out soon if there are no further changes in the policy.

It is deceptive to draw general conclusions of the effects of agricultural reforms on agricultural income on the basis of aggregate results only. As presented in Figure 9.11.a, the impacts of the Agenda 2000 reform in Southern Finland is negative. The national aid paid for livestock production in Southern Finland decreases gradually in 2000-2003, which affects the profitability of livestock production. Agricultural income increases by 8% in Southern Finland in 2000 partly because of increasing CAP support and because the LFA support is now also paid in support area A (Figure 9.11.a). From 2000 to 2010, however, the agricultural income in Southern Finland decreases by 25%. In Figure 9.11.b it becomes evident that farmers in Southern Finland cannot affect much this negative development by the means of optimising, i.e. the agricultural income in Southern Finland in 2010 is highly insensitive to the flexibility constraints. This is understandable, since the feed use of animals can be adjusted close to optimum in a ten-year period in all sensitivity scenarios. In the sensitivity scenarios 1-3, however, feeding adjusts faster than in the Agenda 2000 scenario. Hence, the decrease of agricultural income is slightly slower in the sensitivity scenarios 1-3. In the end of the simulation period the feeding of animals is almost identical in all sensitivity scenarios. This is because the boundary of the feasible region of feeding is reached. For example, bovine animals need some roughage in the feeding and not all roughage can be replaced by grain-based feedstuffs.

Adjusting only the number of animals does not actually improve the profitability of the production. A faster decrease in production (than occurs in the

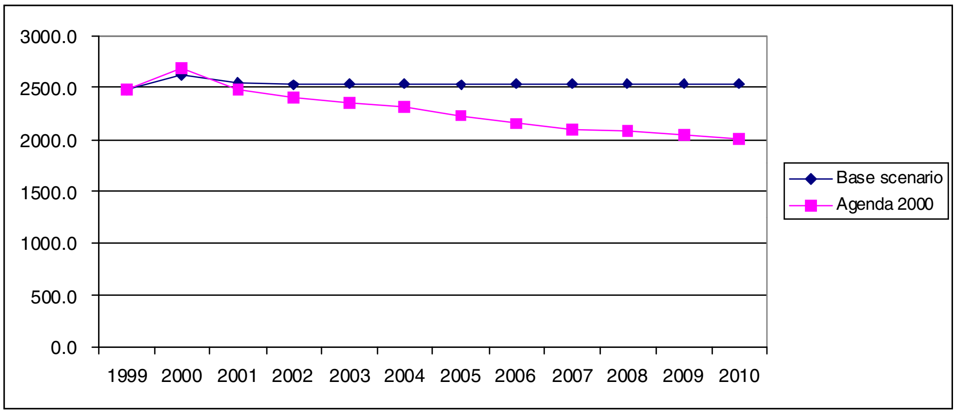

Figure 9.11.a. Total agricultural income of basic agriculture in Southern Finland (FIM million).

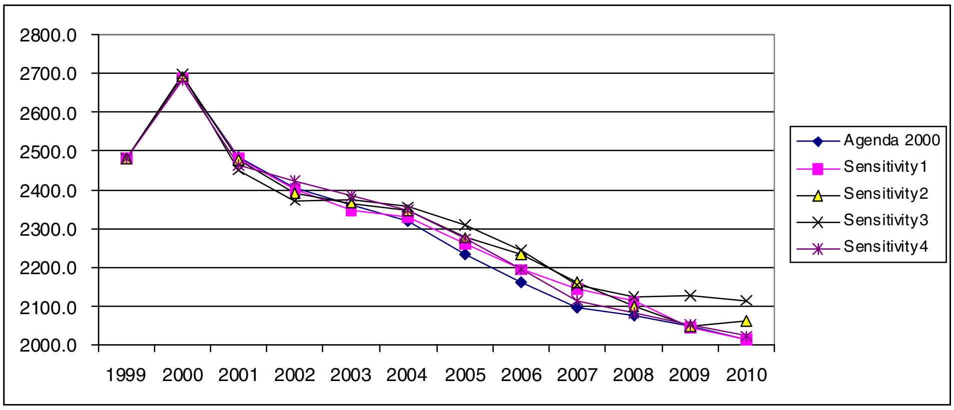

Figure 9.11.b. Sensitivity of agricultural income in Southern Finland to the flexibility constraints.

model outcome) would be possible in the sensitivity scenarios 1-3. It turns out, however, that the production is not equally unprofitable in all sub-regions in Southern Finland. Hence, the increase of the number of animals and hectares of crops in some sub-regions in Southern Finland partly compensates for the decreasing production in some other sub-regions. Thus there is a slightly higher agricultural income in Southern Finland in sensitivity scenarios 2 and 3 than in the Agenda 2000 scenario and in sensitivity scenarios 1 and 4.

Agricultural income is positively influenced by the Agenda 2000 reforms in all other major regions except Southern Finland. In Central Finland the agricultural income is FIM 200-250 million higher in the Agenda 2000 scenario than in the base scenario in 2000-2005. The dairy reform starting in 2005, however, will decrease the agricultural income in Central Finland to the level of FIM 1,050 million in 2010, which is FIM 150 million higher than in the base scenario (Figure 9.12.a).

The level of the agricultural income in Central Finland is to some extent sensitive to the flexibility constraints in the medium term, i.e. more careful optimisation of farmers may improve considerably the aggregate agricultural income until 2010 (Figure 9.12.b). If the maximum rate of change of the production variables is increased by 100% (in sensitivity scenario 3) agricultural income will increase by 10% compared to the actual Agenda 2000 scenario. If the maximum rate of change of the production variables is decreased by 50% agricultural income will decrease by 4% compared to the actual Agenda 2000 scenario. Thus the farmers may benefit by 10%, on the aggregate, when per-

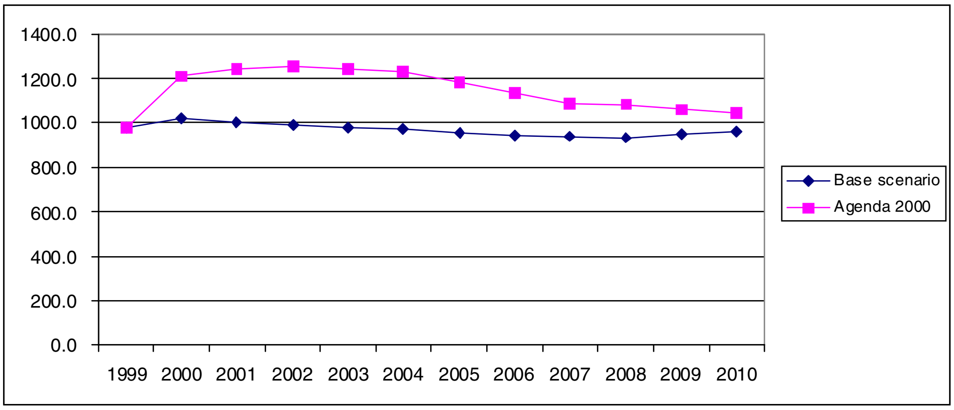

Figure 9.12.a. Total agricultural income of basic agriculture in Central Finland (FIM million).

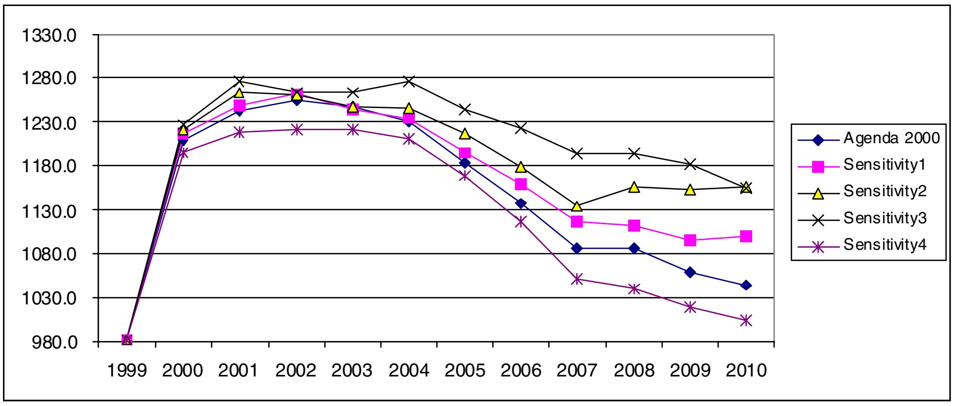

Figure 9.12.b. Sensitivity of agricultural income in Central Finland to the flexibility constraints.

forming better optimisation. One should note, however, that the optimisation is applied only on the number of hectares, number of animals, and feeding variables, while efficiency and productivity development is given exogenously. Hence, higher incomes and production quantities can be achieved by investing more heavily in modern labour and capital saving production techniques. Thus the optimisation discussed here refers to the optimisation when using the given production equipment.

The greatest benefit of all regions from the Agenda 2000 reforms is obtained in Ostrobothnia. In 2010 the agricultural income in Ostrobothnia is 24% higher in the Agenda 2000 scenario than in the base scenario (Figure 9.13.a). In 2000 agricultural income increases by 19% compared to year 1999. The income increases until 2002, remains relatively stable in 2003 and 2004, but decreases

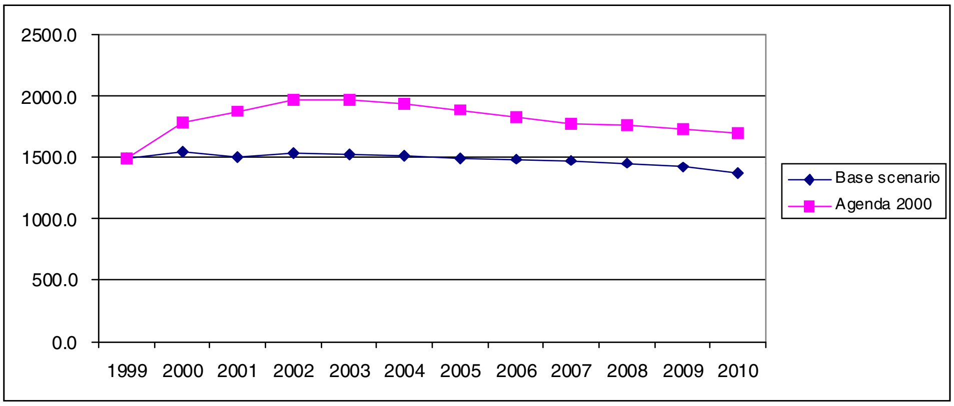

Figure 9.13.a. Total agricultural income of basic agriculture in Ostrobothnia (FIM million).

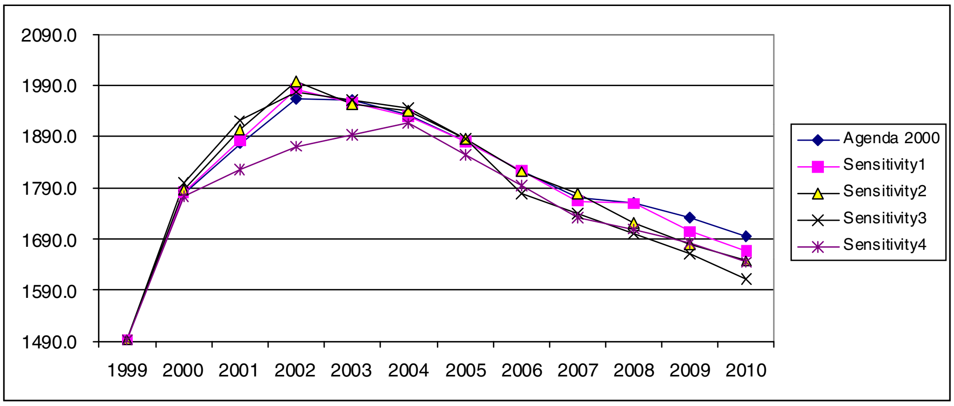

Figure 9.13.b. Sensitivity of agricultural income in Ostrobothnia on the flexibility constraints.

gradually mostly due to the dairy reform after 2004. During 2000-2005, however, the additional income due to Agenda 2000 (compared to the base scenario) is as high as FIM 500 million in Ostrobothnia. Agricultural income decreases only slightly after 2007, which indicates the adjustment to the dairy reform.

It turns out that agricultural income in Ostrobothnia is not sensitive to the flexibility constraints. This means that farmers can gain relatively little by greater adjustments of the number of hectares, number of animals and the feeding variables. In sensitivity scenario 3 the allowable range of change of the production variables is increased by 100% compared to the actual Agenda 2000 scenario, and only slightly higher agricultural income is obtained in 2000-2004. Thereafter, agricultural income decreases slightly faster in sensitivity scenarios 1-3 than in the Agenda 2000 scenario due to the more rapid decrease in the number of animals. The optimal feeding practices can be found quite soon but it is not enough to compensate for the decreased profitability due to Agenda 2000 dairy reform starting in 2005. In 2010 the agricultural income is 5% lower in sensitivity scenario 3 than in the actual Agenda 2000 scenario. As expected, the agricultural income in sensitivity scenario 4, where the maximum rate of change of the production variables is decreased by 50%, responds more sluggishly to policy changes than the agricultural income in the other scenarios.

In Northern Finland the amounts of support are higher than in other parts of the country. This is due to very unfavourable natural conditions for agricultural production. The support paid for milk production cover quite well the high production costs in the north. The productivity growth and the increase in the production efficiency, which are assumed the same, in relative terms, in all parts of the country, fully compensate for the inflation of input prices. Hence, the agricultural income is very stable in the base scenario in 2000-2010. There is some increase in the agricultural income in Northern Finland in 2000 and 2001 when fully adjusting to the 1999 policy in the base scenario (Figure 9.14.a).

Adjustments to Agenda 2000 policy reforms result in higher agricultural income in Northern Finland. Agricultural income rises up to FIM 390 million in 2004, which is 28% more than in 1999 and 34% more than the agricultural income in the base scenario. The dairy reform, however, will lead to a decrease in the agricultural income, which stabilises to FIM 350 million by 2010. There is no downward trend in agricultural income in Northern Finland in 2010, as is the case in all other regions. One may thus conclude that the agricultural income of FIM 350 million represents an “equilibrium” level of agricultural income in Northern Finland, based on the Agenda 2000 policy reforms with the given inflation, productivity and production efficiency development.

As was the case in Central Finland, in Northern Finland farmers may also benefit from more careful optimisation in terms of the number of animals, the number of hectares of different crops and the feeding variables. In other words, agricultural income is sensitive to the flexibility constraints imposed on the

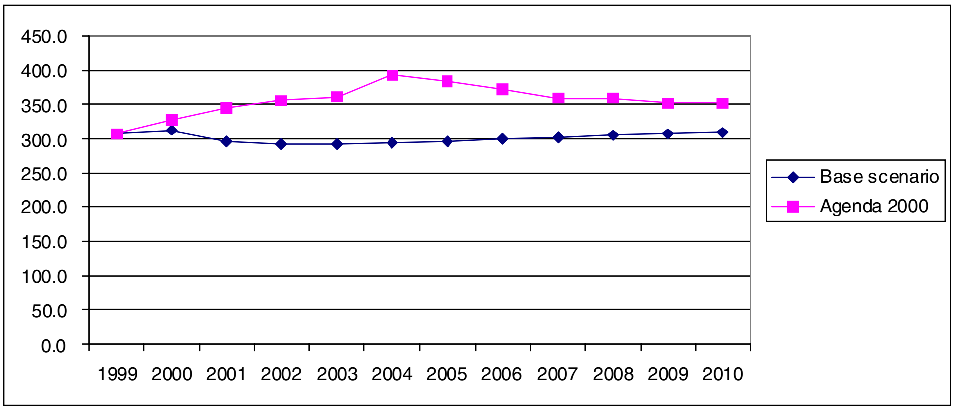

Figure 9.14.a. Total agricultural income of basic agriculture in Northern Finland (FIM million).

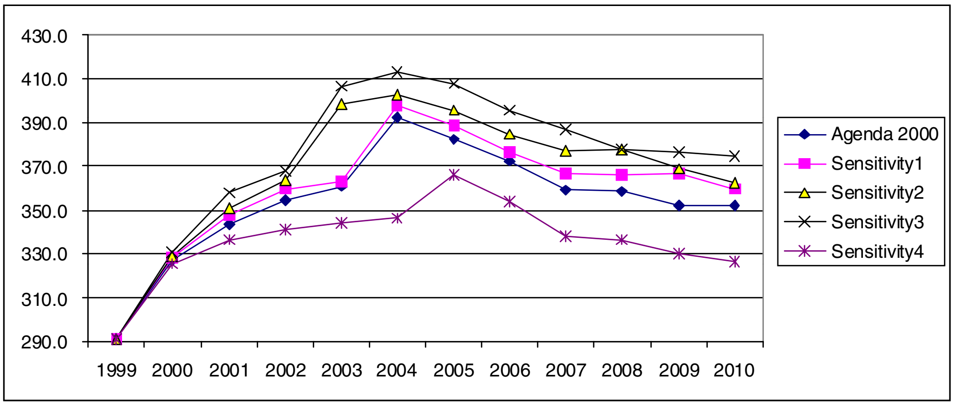

Figure 9.14.b. Sensitivity of agricultural income in Northern Finland to the flexibility constraints.

production variables. It is clearly shown in Figure 9.14.b that more rapid changes in the production variables result in a more rapid increase in the agricultural income from 1999 to 2004 (especially in sensitivity scenario 3), while the decreased maximum rates of change of the production variables will result in lagged adjustments and lagged increase of the agricultural income (sensitivity scenario 4). In sensitivity scenario 3, where the maximum rates of change of the production variables are increased by 100%, the agricultural income in 2010 is 6% higher than in the actual Agenda 2000 scenario. In sensitivity scenario 4, where the maximum rates of change of the production variables is decreased by 50%, the agricultural income is 8% lower than in the actual Agenda 2000 scenario. Hence, one can conclude that farmers in Northern Finland should pay attention to the optimisation using the numbers of hectares of different crops, number of animals, and the feeding variables, since they can reach a higher income by better optimisation.

9.8. Evaluating the success of the Agenda 2000 agricultural reform

The general objectives of the Agenda 2000 agricultural policy reform are as follows (European Commission 1999b):

- to increase the competitiveness of EU agricultural products on the domestic and world markets,
- to integrate environmental and structural considerations
- to ensure a fair income of farmers,
- to simplify agricultural legislation and decentralise its application,
- to improve food safety,
- to strengthen the Union's position in the new WTO negotiations
- to stabilise agricultural spending in real terms at its 1999 level
- to ease eastern enlargement of the EU

Related to rural development, the goal of Agenda 2000 (the agricultural and rural policy reform together) was to develop complementary and alternative activities that generate employment, with a view to slowing the depopulation of the countryside and strengthening the economic and social fabric of rural areas, as well as to improve living and working conditions and promote equal opportunities. It is also seen that the strength of the agricultural sector in the Union rests on its diversity: its natural resources, its farming methods, its competitiveness and income levels, and also its traditions (European Commission 1999d). One goal of agricultural policy of the EU is to maintain this diversity, i.e. to maintain the agricultural production also in the less favoured areas.

Some of these goals, like agricultural spending, simplification of the EU legislation, and EU's position in the WTO, concern the entire EU. As discussed in Chapter 2, Finland must be considered a less favoured area of agricultural production. Hence, the conclusions concerning the expected success of the Agenda 2000 based on the model results are only valid in Finland, and possibly in some other similar less favourable agricultural areas in the EU.

One goal of the Agenda 2000 is to increase the competitiveness of EU agricultural products and to make EU less vulnerable in WTO-negotiations by decreasing product prices. Many agricultural economists, however, believe that Agenda 2000 improves EU's position on the world markets and in the WTO only slightly (Agra Europe 1999c). It is also stated by some agricultural economists that the price reductions of the Agenda 2000 are all too inadequate when integrating Eastern European countries into the EU (Agra Europe 1999a, 1999b, 2001). However, when seen from the Finnish point of view (Finland is a relatively less favourable agricultural area), any liberalisation of agricultural trade is likely to decrease the profitability of production, farmers' income and also production quantities. According to the model results, however, farmers' income increases slightly and production of some products (grain) increase in the Agenda 2000. Hence, Agenda 2000 can be considered positive compared to the expectations or to the base scenario.

According to the model results Agenda 2000 results in a larger cultivated area than the base scenario. This can be considered positive if consumers appreciate domestic crop products as well as an open landscape and cultural values related to crop cultivation. In terms of milk and beef production (which are closely connected), however, Agenda 2000 will result in lower production volumes than the base scenario. Considering both producers and consumers this must be considered a negative effect. According to a survey made in November 2000 (Lihatalous 2/2001, p. 44), a majority of Finnish consumers accept only domestic meat. Consumers are very suspicious of the quality of imported beef.

Even though the agricultural income is slightly increased by the Agenda 2000 the incentive to produce high quality products is endangered because of decreasing prices and high production costs. Passive production methods and cost minimisation may become more popular among farmers. Even though the Agenda 2000 slightly increases farmers' income farmers are now more dependent on public support and more vulnerable for policy changes.

On the other hand, decreasing product prices and increasing per hectare and animal payments due to Agenda 2000 will result in more extensive production practices (less fertiliser is used etc.). This, together with some additional obligations imposed on farmers, will decrease the negative environmental effects of agriculture.

On the basis of the model results the Agenda 2000 agricultural policy reform results in a larger cultivated area and to a smaller area of idled land compared to the base scenario. Hence, it is likely that the Agenda 2000 results in a larger number of farms than the base scenario. The difference in the cultivated area in 2010 between the scenarios is relatively small (8%), however. A rapid farm size growth is necessary in order increase production efficiency and lower the production costs, as discussed in chapter 8.6. The farm size needs to grow by close to 100% until 2010 in order to maintain the income and production level in Finnish agriculture. If the inflation rate is higher than the expected 2% per year assumed in this study, the increase in the farm size needs to be even greater if the income level is to be maintained in agriculture. Hence, the number of farms will decrease close to 50% during 2000-2010 in both policy scenarios. In terms of rural development, it is likely that the Agenda 2000 agricultural policy reform has a small effect on the depopulation of the countryside. The depopulation and the decreasing number of farms is extremely harmful in sparsely populated rural areas where agriculture's share of the local economy is relatively large and agriculture is a major client of many services. If the number of farms decreases rapidly in those areas other sectors of the local economies suffer greatly as well. There is a huge need of additional sources of income outside agriculture on those small scale farms which do not increase production efficiency by the means of large investments.

The decreasing prices of agricultural products and the increasing per hectare and animal payments, decrease the entrepreneurial incentives in agriculture. Agenda 2000 can be expected to result in more extensive production practices which decrease the need of labour in agriculture. This labour input can be used in developing additional sources of income on farm, or used in other professions outside the farm. One may expect the number of farm based rural enterprises, whose main business is not agriculture, to increase in Finland due to Agenda 2000. It is a challenge for policy makers how to promote the success of such enterprises.

9.9. Conclusion of the model results

One must recognise the conditional nature concerning the absolute magnitude of the production volumes and agricultural income presented above. Inflation of the input prices, given efficiency and productivity development as well as the expected price changes of pork and poultry meat, for example, influence the absolute production and income figures obtained from the model. Especially agricultural income is sensitive to the input and output prices, as well as to the subsidies. In the first years of the simulation, however, the production variables are not sensitive to the inflation because of sunk costs representing the co-called "production trap" discussed in Chapter 5. In later years, when all fixed costs become variable in the model, the exogenous inflation rate greatly affects the production and income levels.

The absolute magnitudes of the production variables can be considered as forecasts only if the initial assumptions of the development of productivity, production efficiency and inflation are considered realistic. Furthermore, one should keep in mind that the flexibility constraints imposed on the production variables should also be checked for validity when forecasting the absolute magnitudes of future production and income levels.

DREMFIA model should be used for comparative dynamic analysis of the effects of different agricultural policies, i.e. when assessing the overall aggregate impacts of agricultural policies and trying to assess the overall impact of the actions of many farmers. The model is able to take into account the most important adjustments the farmers can do by means of the given production equipment. The structural and technical change in Finnish agriculture has been, and still is, strongly directed by public policies (MTTL 2000, p. 62-65). Thus there is scope for a model which assumes exogenous technical change and analyses the joint effects of the adjustments made with the given technology. One can evaluate, for example, if the expected structural and technical change is enough to keep the agricultural production and income levels at the level desired by national policy-makers.

The flexibility constraints given for the production variables can be considered as strict technical and biological constraints reducing the scope of optimisation, but also as behavioural constraints. In the results presented above, no econometric or other empirical estimates were given for the flexibility constraints, but an explicit sensitivity analysis was performed. Such a sensitivity analysis showed, in many cases, quite strong results. In some cases the results were robust even when increasing the maximum rates of change of the production variables by as much as 100%. In some cases the results were quite sensitive to the flexibility constraints. For example, the areas of set-aside and idled land, which are the only alternative uses of land in the model for the actual production activities, are strongly influenced if very large annual changes are allowed for the set aside areas.

As already discussed in the beginning of Chapter 9, it would be unrealistic to assume moving equilibrium behaviour of the Finnish agriculture. In particular, the feeding variables seem to respond quite sluggishly to changed price relations of inputs and outputs, as well as to support. Farmers are not, however, for ever stuck with their sub-optimal feeding practices and there are already clear signs of change in the feeding practices of farms. The change in feeding is a slow and gradual process strongly influencing the production and income level of farmers. Together with the changes in fertilisation and the resulting changes in crop yields, the changes in feeding influence land use. The overall profitability of animal farming, which depends not only on feeding, will influence the land use as well. The joint effect of all adjustment processes, with given technology, describes the agricultural development as an off-equilibrium process and offers insights which are not provided by standard static and moving equilibrium models.

One weakness of the base model is the calibration of the production variables using sunk costs. Such an approach is problematic especially in the case of pork and poultry meat production, which are characterised by large fluctuations of product prices. Because of sunk costs the production responds sluggishly and in a lagged manner to price and policy changes. The actual production levels of pork and poultry in the ex post period 1995-1999 could be achieved only by making major adjustments in the level of sunk costs. Thus a high level of sunk costs were needed in order to explain the high level of production despite the lower prices and profitability. In pork production the share of fixed costs suddenly increases from 0 to 65% in 2000, since the production declined in 2000 despite of increased prices and profitability. In later years the level of sunk costs was decreased linearly to the level of investment subsidies.

This kind of calibration is problematic, since it is only the last observation of the production volume or a well-grounded short-term forecast (obtained from the experts who know well the individual markets) which determines the level of sunk costs. The model must be calibrated close to this level of production, at least approximately, in order to make policy analysis. If the pork production volumes, for example, are very different from the actual ones in the ex post period, the policy analysis is difficult. Pork production also influences crop areas and incomes in the ex post period and later periods. Hence, some calibration is necessary using the sunk costs. In the case of pork production this leads to large fluctuations of sunk costs in the ex post period. The level of the sunk costs in the end of the ex post period influences the production variables in later time periods. The problem is that the actual reason for the difference between the actual production and the production variables in the model may not be only the level of sunk costs, but also a lagged production response (which is not always the same as "sunk cost behaviour"), or some random factors, like problems with animal diseases. Thus the large fluctuations in the sunk costs used in calibration may not represent only the actual sunk costs in the case of pork and poultry, in particular, but also some random factors influencing the production response.

The chosen specification of sunk costs is logical, however, since it assumes all fixed costs to be included in the decision-making of farmers until 2010. Thus the rationality of farmers is emphasised. It is also logical (at least from a Bayesian point of view) to use the last observation of prices and production levels in setting the level of sunk costs in calibration. There are few alternatives for this kind of calibration in a model where an exogenous technical change and a myopic aggregate behaviour is assumed, and no long-term strategic investment decisions are made.

The exogenous technical change is appropriate when analysing different scenarios of technical change. In general, however, the assumption of exogenous technical change is somewhat restrictive and problematic. The actual investment decisions are always made by individual farmers even if strongly influenced by public policies. Different agricultural policies do not automatically lead to identical levels of efficiency development and sunk costs assumed when calculating the results presented above. While some part of technical change is endogenous in the base model, like some part of crop and animal yields, the efficiency development is not. As discussed in Chapter 5, the aggregate level investments are one of the least successful areas in empirical economics. One solution to the problem of aggregate level investments is the extended version of DREMFIA model.

10. Application 2: Sensitivity and policy analysis applying endogenous technology diffusion

In the Finnish agriculture technical change is largely a policy variable because of the publicly financed and controlled investment aid system. However, in the investment aid system it is only required that the investing firm must be large enough. No strict regulations on the technological choices are given. At the same time, there are alternative technological choices, different from the dominant techniques, available for farmers. Hence, a detailed analysis of technical change requires endogenous investments and technical change. It is of interest to agricultural economists and policy-makers to analyse if the new alternative technological alternatives can help Finnish farmers to overcome the problem of high production costs and structural deficiency (MTTL 2000, p. 18-21). Thus there is scope for a model which describes the technological choices and the adoption of the alternative technologies. In the context of a dynamic dis-equilibrium model the adoption of new techniques is modelled as a process of technological diffusion as presented in Chapter 6. In this study, however, the diffusion module is only applied for dairy sector. The results of the extended model provides an additional point of view on the adjustment process of agriculture.

10.1. Technological alternatives

Technological alternatives with detailed input use specifications are needed in the technology diffusion model. The technological alternatives to be analysed are represented by farm models presented by Ala-Mantila (1998). The technological alternatives are represented by 3 dairy farm types with 16, 32 and 64 dairy cows, respectively. Each of the farm types uses different production practices and technology. A dairy farm of 16 cows, which is an average size of the dairy herds in Finland in 2000, represents a typical small-scale family farm where the share of labour costs of all production costs is relatively large. A dairy of farm with 32 dairy cows needs a higher level of mechanisation because of the limited family labour input available. Bigger tractors and other machines and larger buildings are required on such a farm than on a farm with 16 cows. A farm with 32 dairy cows may also need some hired labour in peak periods. The basic technological innovations used on a farm with 32 cows are quite similar, however, compared to a farm with 16 cows. Labour is used in quite an efficient manner on a farm with 32 cows. A larger scale of production, even with the same technological innovation, decrease the capital costs per dairy cow.

A dairy farm with 64 cows represents relatively efficient production technology. The basic technological innovations are different on these farms compared to farms with 16 or 32 cows. Work input per cow is lowered by using partially automated milking, feeding, and manure handling systems. The use of such automation is possible on large farms where the costs are divided between an adequate number of dairy cows. Hired labour is a rule on family farms with 64 dairy cows. There is often a full-time employee on such a farm. In addition, some more hired labour and machinery may be used in peak periods. A large share of feedstuffs may be bought outside the farm. The production buildings are of different design on large farms compared to small farms.

The production costs per a litre of milk produced on farms of different size are compared by Ala-Mantila (1998). The production costs, assuming that product prices and prices of primary inputs are the same on all farms, are 20%, and 30% lower on farms with 32 and 64 cows, respectively, than on farms with 16 dairy cows. The use of labour per cow is significantly lower on farms with 32 and 64 cows compared to a farm with only 16 cows. Despite the higher costs per an hour of labour on large farms because of hired labour, the total labour costs per cow are still much lower on large farms than on small farms. On farms with 32 cows the labour costs per a dairy cow are 23% less than the labour costs per a dairy cow on farms with 16 dairy cows. On farms with 64 cows the labour costs per a dairy cow are 53% less than the labour costs per a dairy cow on farms with 16 dairy cows. Since the large farms substitute capital for labour, the capital costs per dairy cow is relatively less dependent on the farm size than the labour costs per dairy cow. On farms with 32 cows the capital costs per dairy cow are 22% less than the capital costs per dairy cow on farms with 16 dairy cows. On farms with 64 cows the labour costs per dairy cow are 50% less than the labour costs per dairy cow on farms with 16 dairy cows. The total of all costs, excluding the feed costs, is 22% and 37% lower on farms with 32 and 64 cows, respectively, than on farms with 16 dairy cows.

Some production risks are higher on large farms than on small farms. For example, if there is a temporary failure in electricity supply, for some reason, all the cows have to be milked by hand or by some back-up system. Back-up systems impose additional costs to farmers. Such risk considerations are not taken into account in the calculations of Ala-Mantila (1998). The production

Table 10.1. The production costs of milk per dairy cow (%) on different farm types. Calculated using Ala-Mantila (1998).

	16 cows	32 cows	64 cows
Labour costs	100	77	47
Capital costs	100	78	69
Overhead	100	85	73
Total (excl. Feed costs)	100	78	64
Total (incl. Feed costs)	100	81	69

Table 10.2.a. Share of cows (%) in different farm size groups in 1995 and 1998.

	1-19 dairy cows		20-49 dairy cows		50- dairy cows	
	1995	1998	1995	1998	1995	1998
Region 1	74.9	62.8	23.4	35.5	1.7	1.8
Region 2	83.2	73.9	16.4	25.2	0.4	0.9
Region 3	74.2	60.3	25.2	38.4	0.6	1.3
Region 4	80.6	67.6	19.2	31.8	0.1	0.1
Whole country	78.1	66.6	21.1	32.1	0.8	1.2

Source: TIKE 1996, 2000.

specifications of Ala-Mantila (1998) presented in Table 10.1 are taken directly as technological choices in this application of the extended model with technology diffusion.

Initial values are required for the initial capital in each of the production techniques. The initial values are calculated by dividing Finnish dairy farms to three farm size classes representing the three production techniques. Farms smaller than 20 cows were aggregated into a group representing *alpha* technique, i.e. a farm with 16 cows in Table 8.12. A second group *beta* (representing farms with 32 cows) was set up by aggregating dairy farms with 20-49 cows. A third group *gamma* (farms with 64 cows) represents farms with more than 50 cows. Using Farm Register (1995, 2000) the number of cows in each farm group were calculated in each main region (Table 10.2.a). The total capital employed in dairy production facilities was estimated by multiplying the annual fixed costs of dairy production by factor 20 (representing the average age of the production facilities in years). The total capital was shared between the farm size classes on the basis of the number of animals. This procedure gives a rough estimate of the capital embodied in different technologies in 1995, which is the

Table 10.2.b. Share of dairy farms (%) in different farm size groups in 1995 and 1998.

	1-19 dairy cows		20-49 dairy cows		50- dairy cows	
	1995	1998	1995	1998	1995	1998
Region 1	88.2	81.2	11.7	18.5	0.2	0.3
Region 2	92.7	86.7	7.2	13.1	0.0	0.2
Region 3	85.9	77.4	14.0	22.2	0.1	0.3
Region 4	89.7	81.5	10.2	18.4	0.0	0.1
Whole country	89.4	82.4	10.5	17.3	0.1	0.2

Source: TIKE 1996, 2000.

initial year of the simulation. Such an estimate is slightly wrong by definition because less capital is needed per cow on large farms than in small farms. The absolute amount of capital is irrelevant in the analysis, however, because only the relative shifts of capital between the technologies over time are analysed here, not the absolute quantities of capital.

There was considerable excess capacity on dairy farms in 1994 due to fixed production quotas and the increase of milk yields per dairy cow. In other words, there has been excess capital on dairy farms since not all animal places could be used because of the fixed quotas (Niemi et al. 1995, p. 174). The quota system was made more flexible after 1996 when many small farms exit production and the larger farms receiving investment aid were able to obtain more quotas. In the simulation it was assumed that there is 20% excess capital, i.e. excess number of animal places on all dairy farms in 1995. The amount of capital is thus expected to decrease in the simulation.

10.2. Parameters of the technology diffusion model

The parameters of the technology diffusion model are depreciation rate, the interest rate of the general economy, and the propensity to invest in alternative, more profitable production techniques.

The technological alternatives include buildings and machinery. Buildings have typically a long duration, say 20-30 years, and low annual depreciation rate, say 4%. Machinery, on the other hand, is less durable than production buildings. A typical duration of machinery is 10-14 years in agricultural production with annual depreciation rates of 7-10% (Ala-Mantila 1998).

In this application, however, no distinction is made between machinery and buildings in the technological alternatives, but a fixed depreciation rate is applied for each technological alternative. This means that some “average” annual depreciation rate is used for all alternatives. Since the actual duration and depreciation rate are somewhat uncertain, two different depreciation rates have been applied. Following the duration of buildings and machinery presented by Ala-Mantila (1998), 6% and 8% depreciation rates are used. The 6% annual depreciation may be considered somewhat optimistic since it suggest an average duration of 16.7 years for each technological alternative and machinery often has a duration of only 10 years. The depreciation rate of 8% suggest a duration of 12.5 years, which, in turn, may be somewhat pessimistic since some machinery, according to Ala-Mantila (1998) can be used up to 14 years, and the machinery still has some resale value (i.e. it can be used longer than 14 years). However, the rate of technological change is dependent on the chosen depreciation rate which determines how fast the existing capacity is wearing off and how fast farmers may actually choose between the alternative techniques. The depreciation rate also affects the profitability of production in the long term.

A reference interest rate is needed for which the rate of return of the different technological alternatives are compared to when making the investment decisions in the model. Since banks are the major suppliers of financial services to farms, the average borrowing rent of Finnish banks have been used as reference rate (BoF 2000).

Interest-rate subsidies and direct subsidies are used as means of subsidising agricultural investments in Finland. The aggregate of the investment aid is included in the savings ratio parameter of the technology diffusion model. This means that the actual savings rate of farmers, assumed to be 100% in this application, is increased by the level of the aggregate investment aid level. The savings ratio represents the money available for investments in the model. Since the investment aid is another source of capital, it can be directly included in the savings ratio. Investment aid is also taken into account when the rates of return of different technological choices are calculated. Investment aid increases the rate of return to the capital of farmers, thus increasing the level of investments. Thus investment subsidies increases the money available for investments as well as the profitability of production, from the farmers' point of view.

In 1995 no investment aid was paid. In 1996-1999, the level of investment aid was, on the aggregate, appr. 26% of the total investment expenditure in northern support areas and 41% in southern support areas A and B. After 1999 investment aid has been of the same level in the whole country, and if the level of the aid remains the same in the northern areas, 26% of the total expenditure of agricultural investments will be paid by the EU and by the State of Finland. It is assumed, for simplicity, that this level of investment aid will be paid until 2010. Thus the savings ratio is 1 in all regions in 1995, 1.26 in northern support areas in 1996-2010, 1.41 in southern areas in 1996-1999, and 1.26 in all areas in 2000-2010.

The propensity to invest in alternative production technologies (parameter η in eq. 6.57 in Chapter 6) is a behavioural parameter in the model, which represents the extent to which farmers are willing to invest their investable surplus, as well as the investment aid, in alternative production techniques. η parameter is varied in order to analyse the sensitivity of the production volumes and the penetration levels of the different technologies to the unknown η parameter values. Five different values of η are used, including one which calibrates the milk production volumes close to the actual levels in 1995-1999. The same values of η are used in two separate cases: depreciations of 6% and 8%.

The lower bound of the number of dairy cows was set to 90% of the number of dairy cows in the previous year. Thus the lower bound does not restrict the model in normal cases since the chosen depreciation rates imposed for the capital (and the number of the animal places) are 8% and 6%. The lower bound becomes binding only if the revenues exceed variable costs, i.e. the lower bound prevents the number of dairy cows falling down to zero. If it occurs in the actual simulation that the number of animals decreases by 10% in some region, this is an indication of the fact that revenues do not cover variable costs. Large drops in the aggregate number of animals, however, are very unlikely in reality, since dairy production cannot be suddenly stopped and then soon restarted because of biological and economic reasons. It is possible only for very few individual farmers to sell all their animals at once when the production is unprofitable, and then to buy all animals at once when the production becomes profitable again. For most farmers such a behaviour would result in an excess number of animals to be slaughtered, as well as in a shortage of live animals. In dairy farming the exit decision is irreversible, since it is difficult and costly to restart production after selling out all animals. For this reason, a lower bound of 90% has been imposed for the number of dairy cows in each region in order to guarantee the realism of the supply response.

The feeding variables are bounded by the same constraints as in the base model, presented in Table 8.10 (in Chapter 8). Thus the feeding system is considered here an independent subsystem of dairy farms not included in the technological alternatives represented by different farm sizes. In fact, linking diets to the farm size would be an error. Diets of animals can also be adjusted independently of the farm size on the basis of the prices of different feed stuffs. Major changes in diets, however, require adjustment of some capital inputs. For example, increasing grain in the feeding of dairy cows means that grain handling machines become of greater importance. Enlarging a farm and changing the feeding machines should be done simultaneously, since first investing to grain handling machines on a small farm and then enlarging a farm would mean a waste of money (grain handling machines of a small farm would be of insufficient capacity for the needs of a larger farm). Hence, investments in the overall farm operations make it easier to change animal diets as well. This kind of complementarity may result in a lock-in effect (Chapter 5.4.3). However, the diets should not be fixed to technological alternatives. Diets and feeding equipment depend on feed prices and can also be changed, at least to some extent, without investing in larger production units.

10.3. Investment and capital levels in different techniques

In the investment function 6.57 the profitability, measured as a rate of return to the invested capital, of each technique is compared to the general interest rate of the economy. If the rate of return is less than the general interest rate, no investment will occur, but the capital stock embodied in the particular technique will decrease by the rate of the given depreciation rate. This means sunk cost behaviour: no fixed costs of that technique are taken into account in the annual optimisation of the consumer and producer surplus. The level of capital in any technique decreases whenever the net investment (actual investment minus depreciation) is negative. The level of sunk cost is proportional to the relation between the investment level and the depreciation: full fixed costs are taken into account only if the capital stock is increasing, i.e. the net investment is positive. This represents rational decision-making of farmers: all production costs have to be covered if the production and capital in the production systems are increased (equations 6.61-6.62).

$$I_\alpha = \sigma r_\alpha K_\alpha + \eta (r_\alpha - r) K_\alpha = \sigma (Q_\alpha - w L_\alpha) + \eta (r_\alpha - r) K_\alpha . \tag{6.57}$$

It is not only the relative profitability of the techniques which determines the level of investment, however, but also the capital embodied in different production techniques (eq. 6.57). This means that inferior production techniques may attract more investments than the superior ones if the initial capital embodied in the inferior techniques is sufficient. Such investment behaviour does not mean that farmers were irrational, but represents heterogeneity of farms in terms of production costs and the imperfect information concerning the low-cost production techniques, as well as a conglomerate of other frictions preventing farmers from choosing the best performing technique. Parameter η represents such frictions, i.e. farmers' willingness to invest in alternative techniques. The depreciation rate determines the rate how fast the existing technique is wearing off, which also determines how fast farmers will shift to better techniques. It is the interplay of profitability, parameter η and the depreciation rate which determines the investments.

Since the investment level depends on the existing level of capital, the increasing or decreasing investments in a particular technique may have a self-inforcing effect that can only be analysed in a dynamic context. Such "non-convexity" is ruled out in static models a priori in order to avoid unbounded or corner solutions. In this modelling exercise self-inforcing patterns of technological change are seen as integral parts of reality, not as anomalies to be avoided.

Since agricultural support changes annually in 1995-2003 and 2005-2008, the profitability of all techniques changes constantly. Consequently, investment and sunk cost levels change as well. There are also non-linearities related to yield functions and to foreign trade specification which affect the profitability during the simulation. It is thus very difficult to solve analytically the final levels of capital in each production technique without running the full model. In other words, the model describes a complex and path-dependent process of economic and technological change consisting of many interactions. Small changes in the early phase of the simulation may accumulate and become large during the simulation. In the following, not all aspects of this sensitivity to initial conditions are analysed, but only to the extent of varying η parameter and the depreciation rate.

Capital levels and investments in alpha technique

The simulation results presented in Figures 10.1.a-b and 10.2.a-b describe how investment and capital levels embodied in alternative milk production techniques change when the η parameter and the depreciation rate is varied. In Figures 10.1.a-b one can see that the capital embodied in alpha technique, i.e. on small dairy farms, is largely unaffected by the η parameter. This is because the alpha technique is inferior to beta and gamma techniques and all investable surplus, if there is any, shifts to beta and gamma techniques even at low η parameter values. The level of capital embodied in alpha technique is primarily determined by the given depreciation rate. In the case of 6% depreciation the capital embodied in the alpha technique is FIM 4.64-4.71 billion.

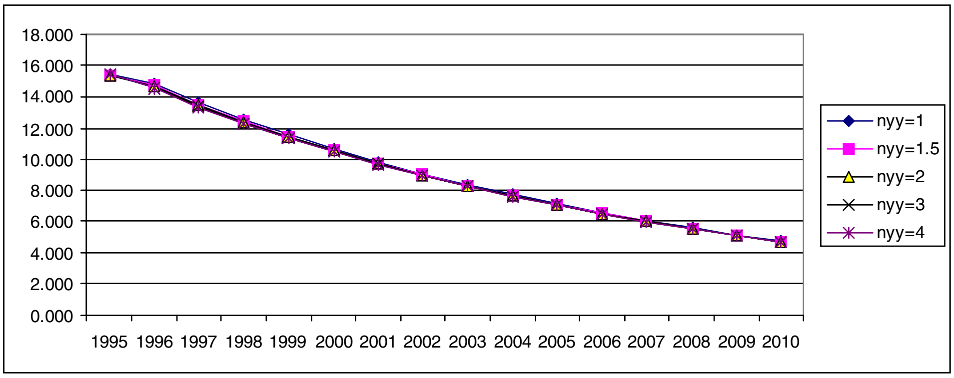

Figure 10.1.a. The capital (FIM billion) embodied in alpha technique (of small farms up to 19 cows) at different values of parameter η. Depreciation rate = 8%.

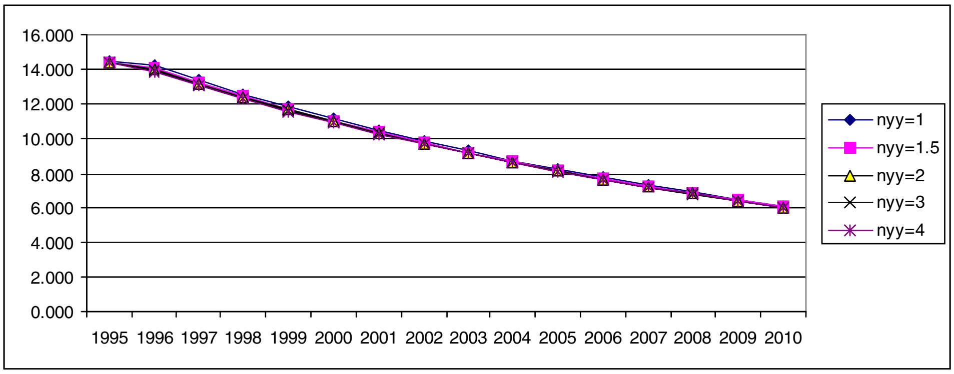

Figure 10.1.b. The capital (FIM billion) embodied in alpha technique (of small farms up to 19 cows) at different values of parameter η. Depreciation rate = 6%.

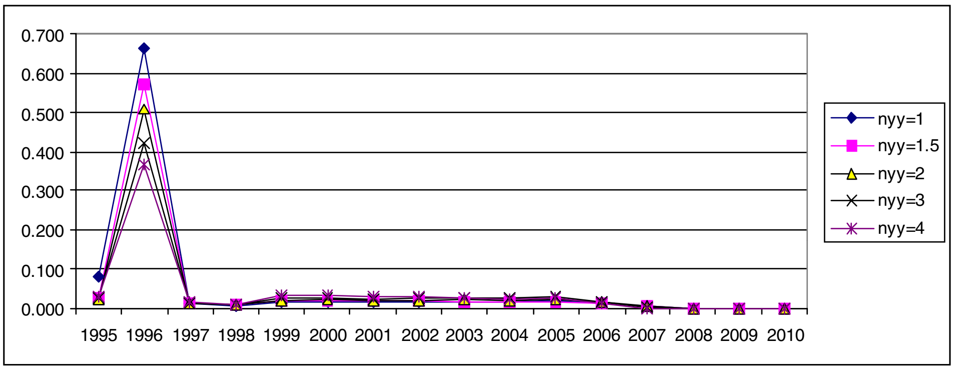

Figure 10.2.a. Investments (FIM billion) in alpha technique (of small farms up to 19 cows) at different values of parameter η. Depreciation rate = 8%.

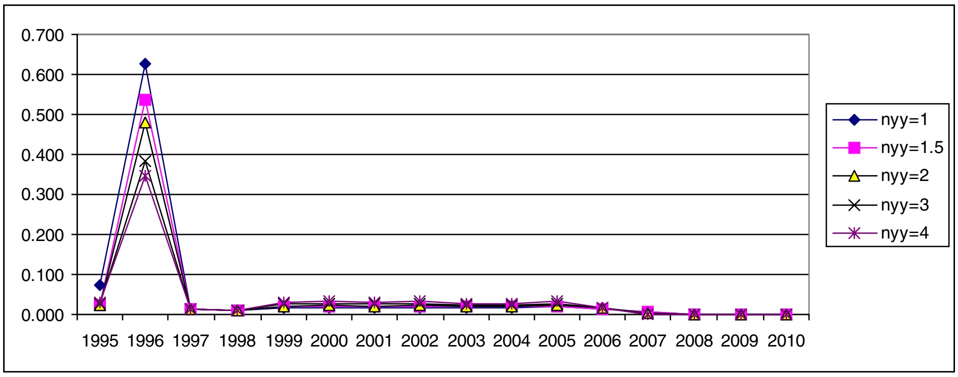

Figure 10.2.b. Investments (FIM billion) in alpha technique (of small farms up to 19 cows) at different values of parameter η. Depreciation rate = 6%.

There are, however, considerable investments in the alpha technique in the early years of the simulation when the shares of capital in beta and gamma techniques are low (Fig. 10.2.a-b). The investments in the alpha technique decrease more rapidly as the η parameter increases, i.e. the investable surplus shifts to other techniques.

Capital and investment levels in beta technique

Beta technique turns out to be the technique absorbing most of the investable surplus. Beta technique is less efficient and profitable than gamma technique, but the beta technique is more attractive because of the wider spread and reduced uncertainty. The final level of capital in the beta technique depends crucially on the η parameter values, as presented in Figure 10.3.a-b. One can already see that high values of η parameter result in unrealistically high investments, since the initial level of total capital embodied in the dairy production systems in 1995 was calculated as FIM 20.5 billion. The capital embodied in beta technique reaches the level of FIM 19 billion in 2010 already when the η parameter is 3. Higher capital values than FIM 20 billion in one technique are unlikely, however, since there were already some excess capital in dairy production in 1995. Since the capital value in dairy production systems depreciates quite slowly, there may be a temporary increase in the capital, but in the long term the capital should be decreasing if farmers were to save any money in the capital costs. Saving labour and capital costs per unit of production are the main incentives for investments in larger production units.

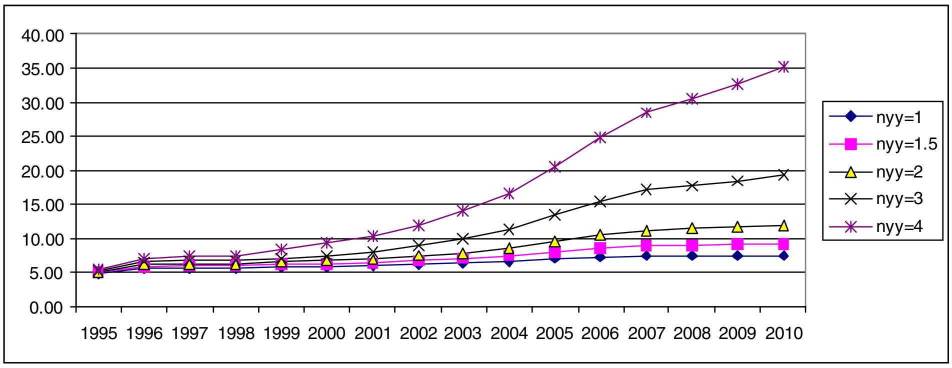

Figure 10.3.a. The capital (FIM billion) embodied in beta technique (of medium-sized farms of 20-49 cows) at different values of parameter η. Depreciation rate = 8%.

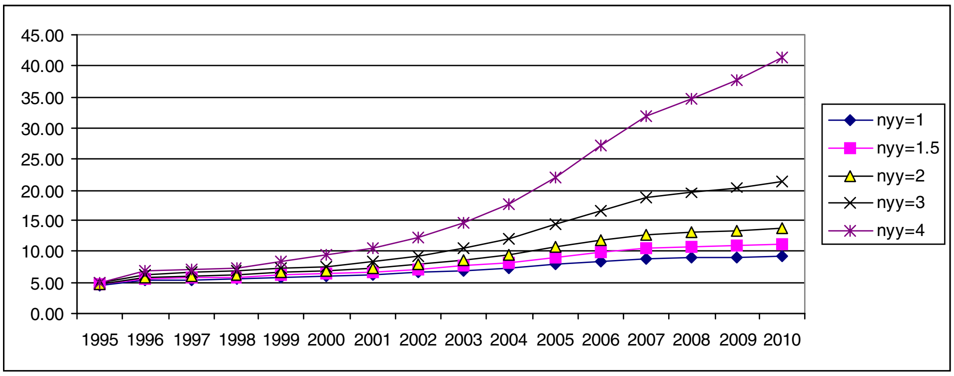

Figure 10.3.b. The capital (FIM billion) embodied in beta technique (of medium-sized farms of 20-49 cows) at different values of parameter η. Depreciation rate = 6%.

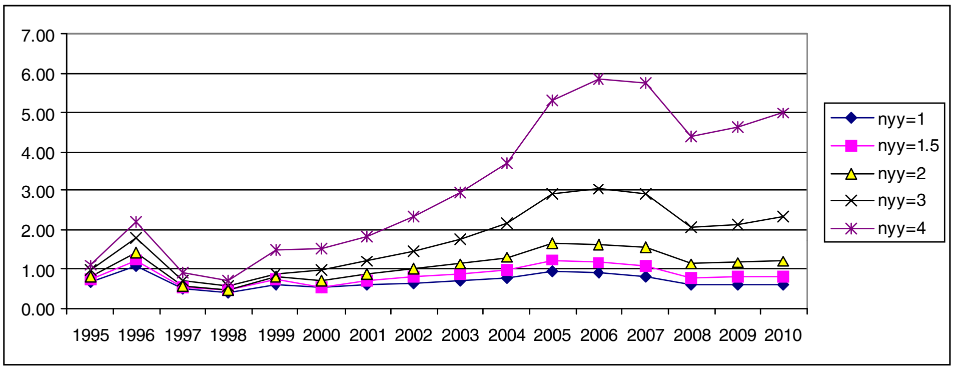

Figure 10.4.a. Investments (FIM billion) embodied in beta technique (of medium-sized farms of 20-49 cows) at different values of parameter η. Depreciation rate = 8%.

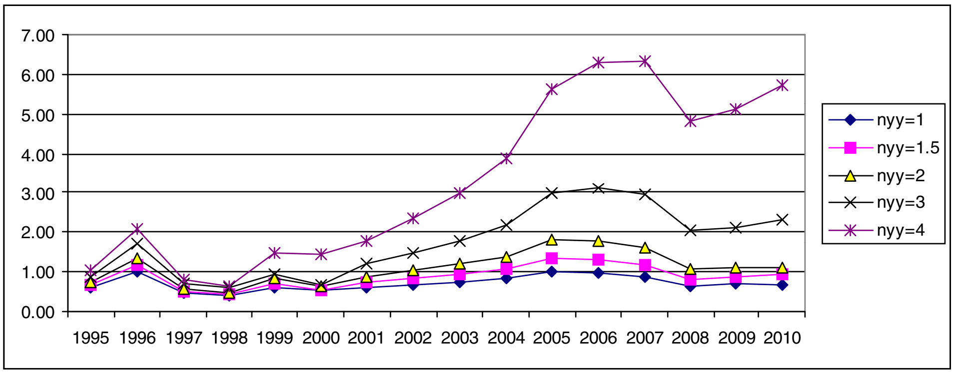

Figure 10.4.b.Investments (FIM billion) embodied in beta technique (of medium-sized farms of 20-49 cows) at different values of parameter η. Depreciation rate = 6%.

One can see in Figures 10.4.a-b that investments in beta technique increase until 2005, but the CAP dairy reform decreases the annual investment levels due to decreased profitability. The investment recovers slightly in 2008-2010. Higher depreciation rate (8%) results in slightly higher investments in beta technique in the early years of the simulation because there is more scope for investments since the production systems are wearing off at a relatively fast rate. In the long term, however, high depreciation rate results in slightly lower investment activity. This is because the depreciation rate, which is the same for all techniques, decreases capital value in all techniques. According to the investment function 6.57, a lower level of capital decreases future investments. In a dynamic setting this reduction in the annual investment level accumulates in the medium term. Hence, the investment levels to beta technique in 2010 are lower in the case of

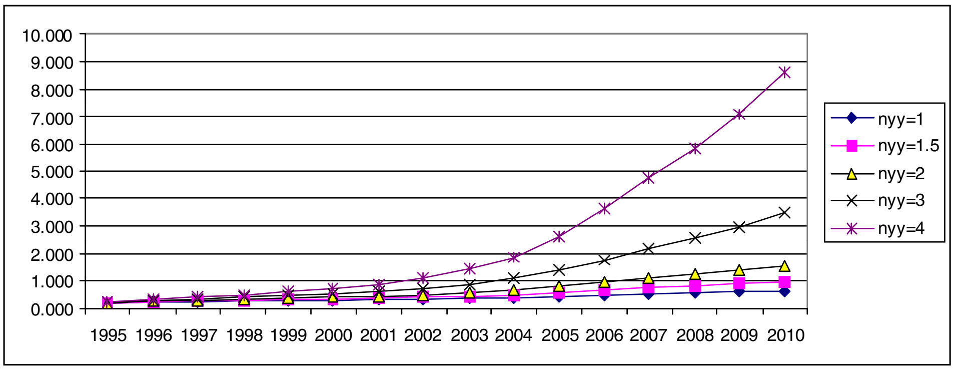

Figure 10.5.a. The capital (FIM billion) embodied in gamma technique (of large farms of more than 49 cows) at different values of parameter η. Depreciation rate = 8%.

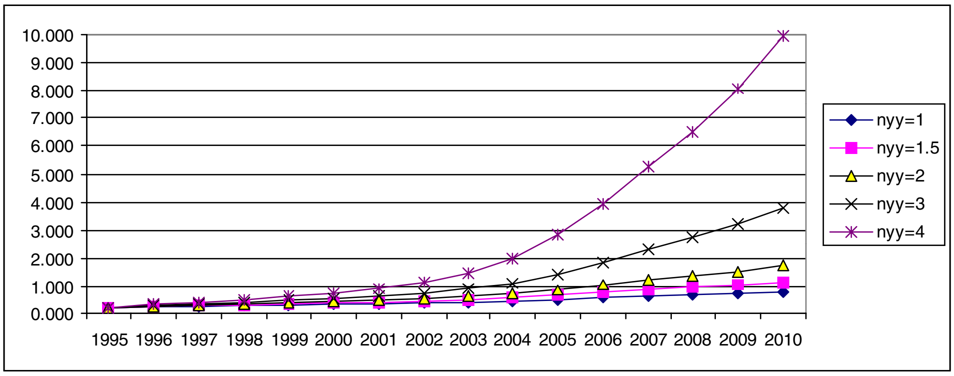

Figure 10.5.b. Capital (FIM billion) embodied in gamma technique (of large farms of more than 49 cows) at different values of parameter η. Depreciation rate = 6%.

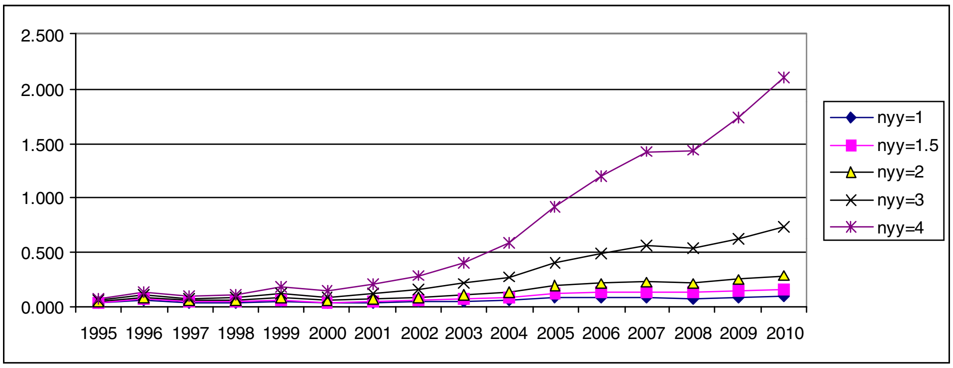

Figure 10.6.a. Investments (FIM billion) in gamma technique (of large farms of more than 49 cows) at different values of parameter η. Depreciation rate = 8%.

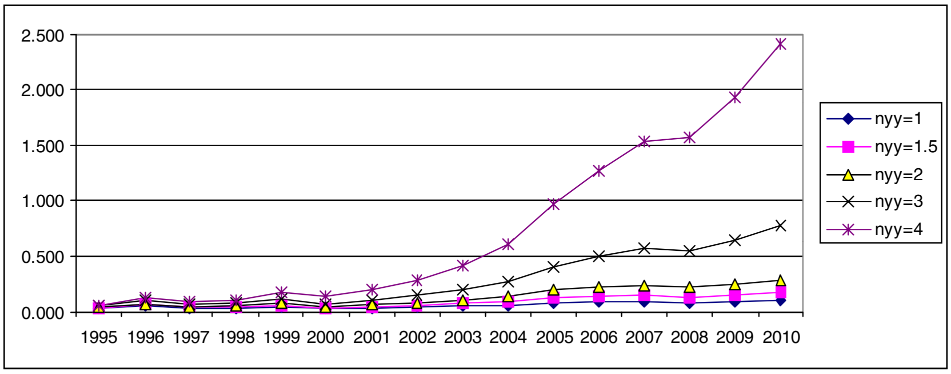

Figure 10.6.b. Investments (FIM billion) in gamma technique (of large farms of more than 49 cows) at different values of parameter η. Depreciation rate = 6%.

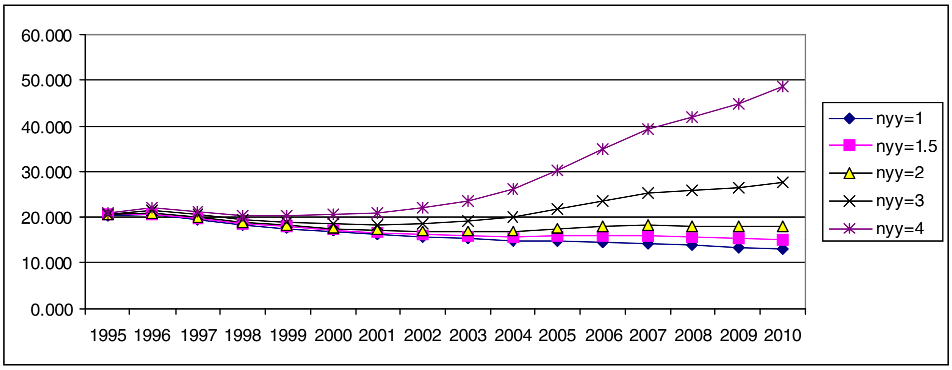

Figure 10.7.a. Capital (FIM billion) embodied in all techniques at different values of parameter η. Depreciation rate = 8%.

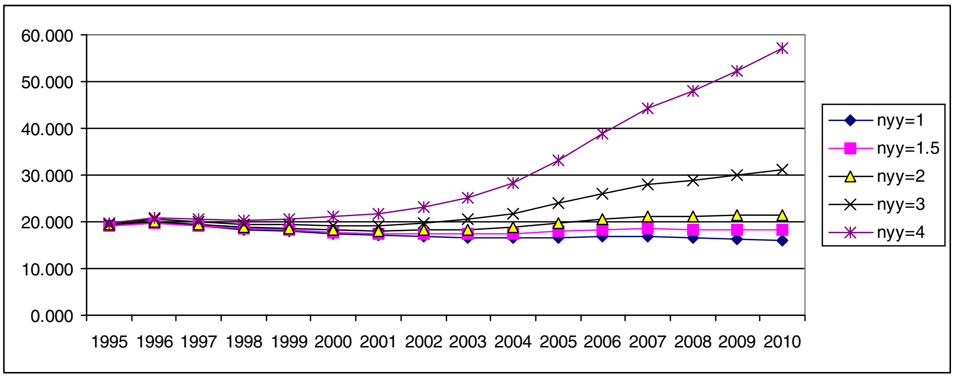

Figure 10.7.b. Capital (FIM billion) embodied in all techniques at different values of parameter η. Depreciation rate = 6%.

8% depreciation rate than in the case of 6% depreciation rate. This result is in line with basic intuition since alpha technique produces only little, if any, investable surplus to be reinvested in beta and gamma techniques. The higher depreciation rate also slows down the growth of capital in beta and gamma techniques.

If the depreciation rate is 8% the total capital in dairy production systems will decline permanently under the level of 1995 if the η parameter is less than 2. If the η parameter takes the value 4, the total capital value soon becomes unrealistically high. High values of η parameter actually mean that the investable surplus is multiplied by a factor greater than 1. In other words, the money for investments may not accrue only from production but also from other sources. One such a source is investment aid, which is already included in the savings ratio. In Finland, where farms typically own some forest, some part of the investment expenditure is forest income. Hence, the increase of capital in dairy production systems is possible, at least temporarily. In the long term, however, the capital embodied in the production systems should decrease if farmers were to save on the capital costs. The results presented here should be understood as "medium-run" results since the duration of the agricultural investments can be as long as 30 years.

10.4. Penetration levels of production technologies

Technological diffusion and penetration levels of different techniques can be measured by the shares of capital embodied in different techniques from the total capital stock. Such penetration levels of the alpha, beta and gamma techniques are presented in Figures 10.8.a-c. The diffusion is faster when the η parameter or the depreciation rate is increased.

According to the qualitative remarks of Soete and Turner (1984, p. 618), a higher depreciation rate will decrease the time it takes for an innovation to diffuse through an economy. This remark is affirmed in this study. In this application the initial capital is much higher in the alpha technique than in the alternative techniques. One could imagine that a higher depreciation (or "scrapping" as Soete and Turner call it) rate gives more scope for the investments to more profitable techniques by decreasing the capital embodied in the inferior techniques at a faster rate. If the same depreciation rate is applied for all techniques, however, the investment function 6.57 implies that a higher depreciation rate will decrease capital in all techniques. The reduction of capital due to a higher depreciation rate is, nevertheless, relatively lower in the better performing techniques than in the inferior ones. Hence, the higher depreciation rate will result in higher penetration level (which measures the relative spread of each technique) of the best performing techniques. The capital in the inferior technique alpha decreases almost always at a rate close to the depreciation rate,

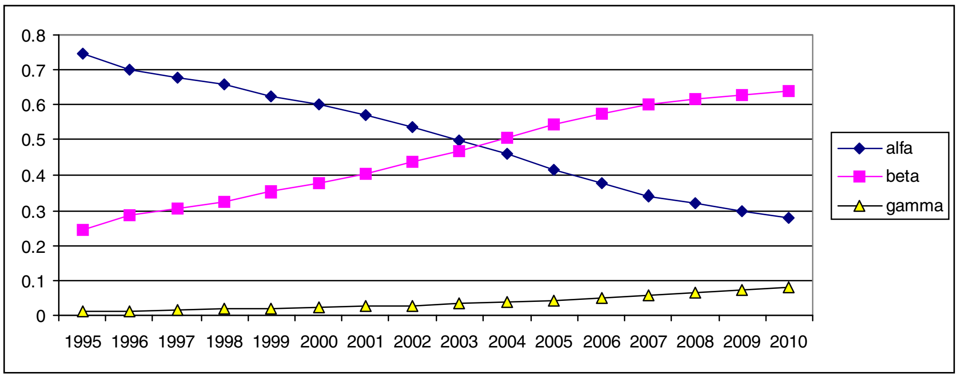

Figure 10.8.a. Share of capital (FIM billion) embodied in different techniques. η*=2, depreciation rate = 6%.*

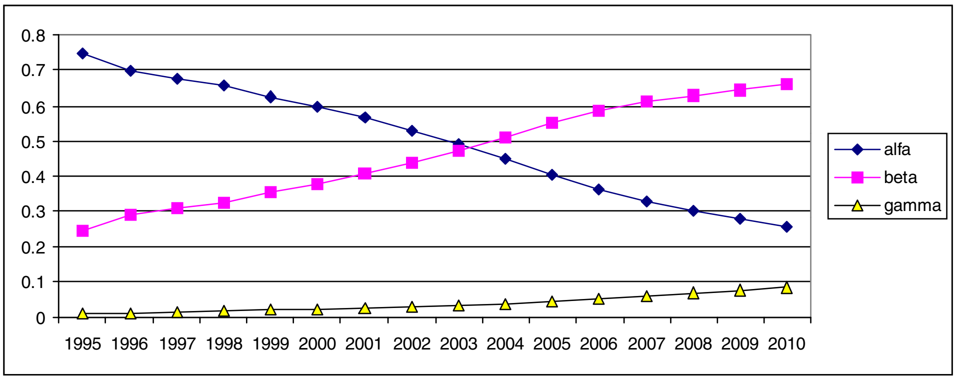

Figure 10.8.b. Share of capital (FIM billion) embodied in different techniques. η*=2, depreciation rate = 8%.*

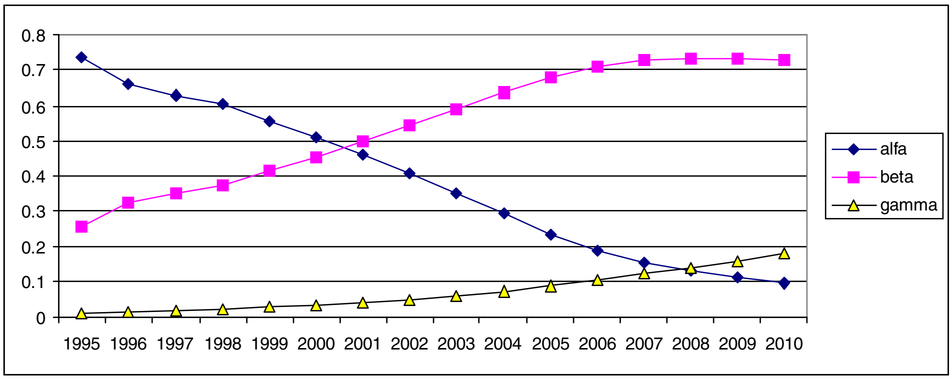

Figure 10.8.c. Share of capital (FIM billion) embodied in different techniques. η*=4, depreciation rate = 8%.*

while the better performing techniques grow continuously. The depreciation rate has relatively less effect on the capital in gamma technique than in beta technique. In this application, however, a higher depreciation or scrapping rate results only slightly more rapid diffusion of innovations. This is due to the fact that alpha technique produces little investable surplus to be invested in the beta and gamma techniques. Hence, a high depreciation rate slows down the absolute investment levels in the best performing techniques while the penetration level, i.e. the share of total capital embodied in the beta and gamma techniques, becomes greater, as claimed by Soete and Turner (1984, p. 168).

The S-shaped form of the diffusion curve (familiar from the diffusion literature) of the beta technique can be observed in Figures 10.8.a-b and 10.9.a-b. The diffusion of beta technique is slow in the early years since alpha technique is still dominant and farmers have imperfect information about beta technique,

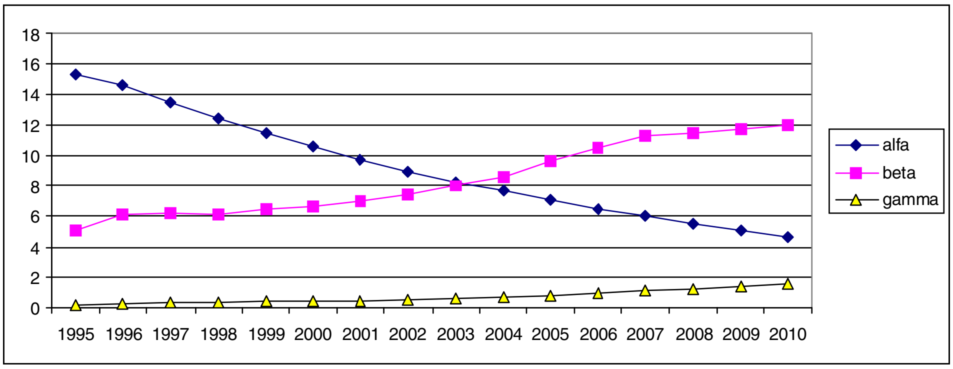

Figure 10.9.a. Capital (FIM billion) embodied in different techniques. η=2, depreciation rate = 8%.

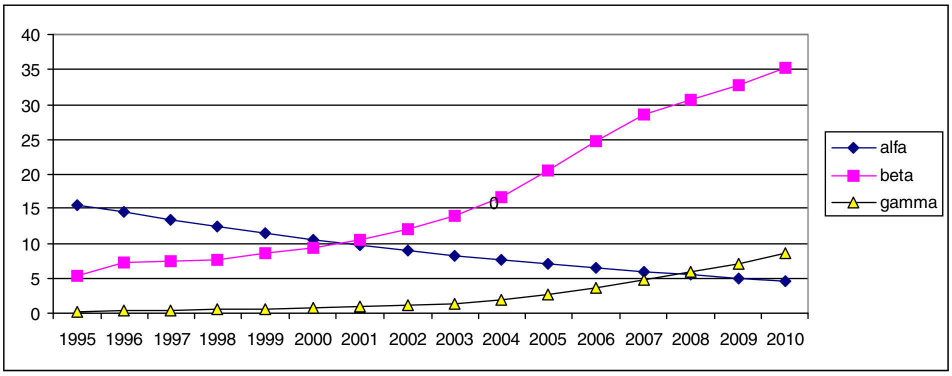

Figure 10.9.b. Capital (FIM billion) embodied in different techniques. η=4, depreciation rate = 8%.

and, in particular, about gamma technique. In later years dairy production becomes relatively unprofitable using the alpha technique, and almost all investable surplus produced by the alpha technique, if there is any, shifts to the beta and gamma techniques. The growth in the capital embodied in the beta technique is self-inforcing by nature since the information about the beta technique becomes more wide-spread. In the last years of the simulation an increasing share of the investable surplus shifts to the gamma technique. In fact, if the η parameter is relatively high, the share of capital in the beta technique starts to decrease in the last years of the simulation when the growth of capital in the gamma technique becomes faster. A decreasing share of capital is still embodied in the alpha technique in the end of the simulation period since all farmers do not have identical perceptions about the benefits of the alternative techniques, and the costs of shifting to those techniques are relatively high on some farms.

10.5. Milk production volumes

The simulated total milk production volume of Finland under different values of the η parameter is presented in Figures 10.10.a-b. The actual production levels in 1995-1998 can be replicated very closely (the difference between the simulated and the actual is only 1.5%, at the greatest) at all values of the η parameter. This is due to sunk costs which are largely unaffected by the η parameter in the early years of the simulation. There was some cumulated excess capital in dairy production systems in 1995 due to increasing milk yields and fixed production quotas, which have resulted in an excess number of animal places available already before the EU membership. 20% excess capacity in 1995 was assumed in this application. The depreciation of this excess capital takes some time and implies sunk behaviour of farmers in the early years of the simulation. The sunk cost behaviour result in a high level of production at all values of the η parameter in the first years of the simulation. Hence, the production volumes of milk are close to the actual production level (2.3 mill. litres) in 1997-1998.

In 1999 the actual production level was increased despite the further decrease of profitability of production (Ala-Mantila 2000, p. 62). The model cannot replicate this increase except at high values of η parameter. High values of η parameter, however, result in higher investments in techniques beta and gamma than actually occurred in reality. In later years the high values of η parameter result in rapidly increasing capital stock in dairy sector, which can be considered unrealistic.

It is obvious that the shifts of capital between only three aggregated major farms groups and technologies are insufficient to explain the increased production efficiency. Production efficiency may also increase without major shifts of

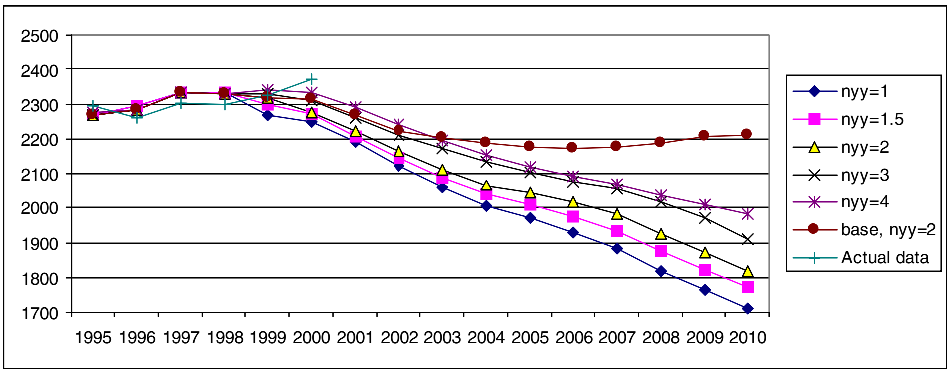

Figure 10.10.a. Total milk production volume (mill. kg). Depreciation rate = 8%.

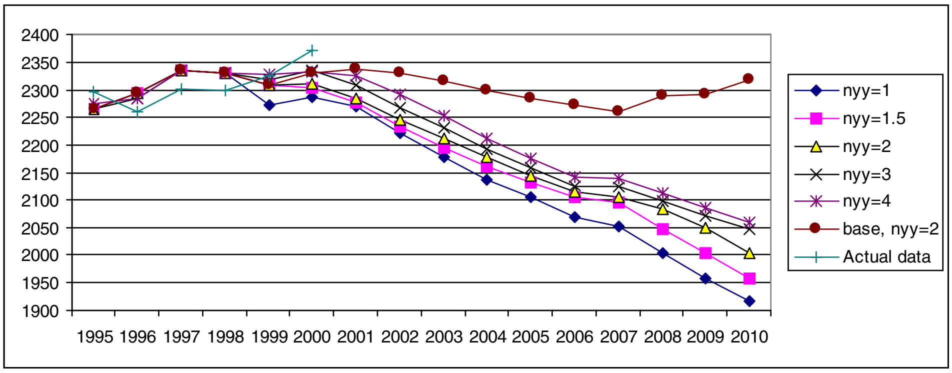

Figure 10.10.b. Total milk production volume (mill. kg). Depreciation rate = 6%.

capital between the major farm groups. Farmers may increase the production efficiency and the farm size at small steps. More techniques or farm size groups are needed in the model in order to calibrate the production volume close to the actual ex post levels. The selection of farms with different production costs in each farm size group may also result in decreased production costs.

The given depreciation rate influences considerably the production volumes in the long term, even though a plausible range of the depreciation rate is quite restricted. This is understandable since the depreciation rate affects the number of animal places in the inferior technique, in particular, which can be used at zero fixed costs. The production volumes are also to some extent sensitive to the values of the η parameter.

10.6. Effects of Agenda 2000 on dairy investments and milk production

Next, a simple policy analysis using the model of technology diffusion is presented. Value 2 was chosen for the η parameter when performing the policy analysis. Other values could have also been chosen, but value 2 was selected since using that value the total capital embodied in dairy facilities will grow only modestly under Agenda 2000 policy. Despite the increased investments on dairy farms in recent years it is not realistic to expect large increases in the capital of dairy production systems in the long term (as is the case when selecting a value of the η parameter higher than 2).

The effect of Agenda 2000 was analysed when selecting depreciation parameter as 6% and 8%. The accumulated capital in the base and Agenda 2000 scenarios is presented in Figure 10.12.

Milk production volumes in base and Agenda 2000 scenarios are presented in Figure 10.11. One can see that Agenda 2000 results in milk production volume that is significantly lower in 2010 than in base scenario. In the case of 6% depreciation rate Agenda 2000 results in a milk production volume that is 300 million kilos less than in base scenario. If the depreciation rate is 8% the Agenda 2000 policy results in 400 million kilos less milk in 2010 than is the case in the base scenario.

According to base model results Agenda 2000 results in milk production volume that is 110 million less than the volume in the base scenario in 2010 (as presented in Chapter 9.3). Hence, the reduction in milk production volume due to Agenda 2000 is significantly larger when the extended model of technology diffusion is used in the policy analysis. This is understandable, since endogenous investments, and, consequently, the efficiency development in dairy production depends crucially on profitability of production (as modelled in 6.57)

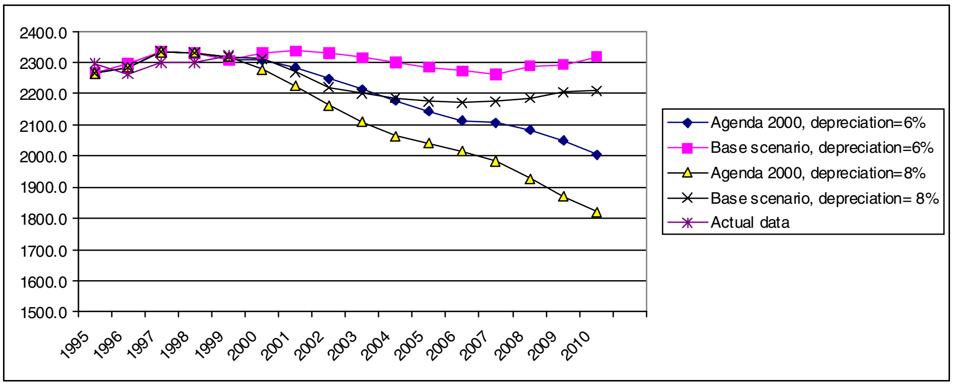

Figure 10.11. Milk production volumes in base and Agenda 2000 scenarios. η parameter = 2.

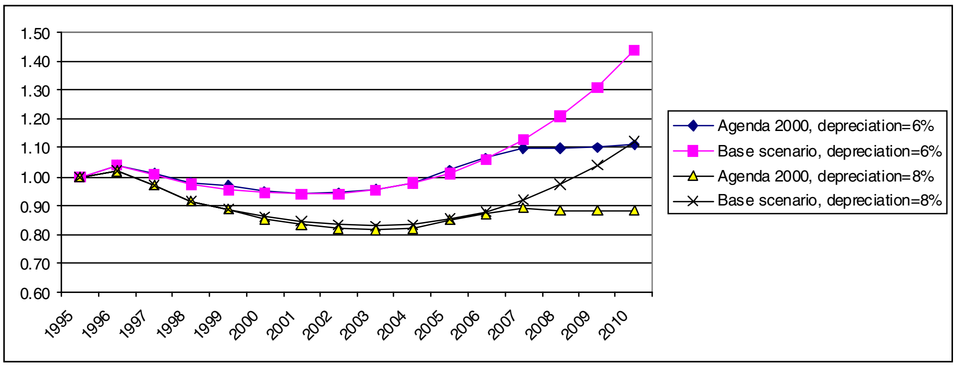

Figure 10.12. Capital (FIM billion) embodied in all techniques at base and Agenda 2000 scenarios. η parameter = 2.

which, in turn, depends crucially on agricultural supports. The decreased profitability of production in Southern Finland in Agenda 2000 scenario results in a slower rate of technical change and production efficiency development compared to the base scenario. In Figure 10.12 one may see that the accumulated capital in dairy facilities is clearly larger in base scenario than in the Agenda 2000 scenario in 2010. The growth of capital in dairy facilities continues in the base scenario but the capital does not increase anymore in the Agenda 2000 scenario after 2007 because of the dairy reform. One may conclude that endogeneous technical change and investments play a significant role in analysing policy effects in the long run.

10.7. Discussion

One can find both advantages and disadvantages in the extended model with endogenous technology diffusion. The major advantage over the base model is the consistent structure of the technology diffusion model and the relaxation of some restrictive assumptions made in the base model. The exogenous technical change and sunk costs, sometimes used in the calibration of the base model, are made endogenous in the extended model. In the extended model the investments and efficiency development of agricultural production are strongly influenced by profitability and thus the policy variables. The investment function of 6.57 assumes rational profit maximising behaviour of farmers. The capital stock in each technique can only increase if the production using the technique is still profitable after all fixed costs.

The model of technology diffusion takes into account the fact that all farmers do not immediately shift to the best performing technique. The model assumes imperfect information relating to the alternative production techniques as well as heterogeneity of farms, which make the population of farmers shift quite slowly to the alternative techniques. The extended model provides S-shaped penetration curves of the new alternative techniques. This is desirable since the S-shaped form is often encountered in empirical research of technological change.

The sunk cost behaviour is directly related to the profitability of production and to investments. The level of investments and sunk costs depend directly on the profitability of production. In the extended model there may be considerable sunk cost behaviour at all phases of the simulation, not only in the first ex post years, as assumed in the base model. For example, if the production is profitable in the early years of the simulation but the profitability decreases later because of reduced support, for example, it is reasonable to expect investments in the early phase of the simulation and sunk cost behaviour later in the simulation period.

The obvious reasons for the increased production volumes in reality are the high share of sunk costs and increased investments in 1996-1999 without rapid changes in the number of large farms. The number of farms with less than 20 cows decreased by 5,900 farms (-20%) during 1995-1998. The number of farms with 20-49 cows increased by 1,500 during 1995-1998, while the number of farms with more than 49 cows increased by only 36 farms during 1995-1998. This means that 4,400 farms with less than 20 cows exited production during 1995-1998. It is obvious that the average farm size increases even without investments when small farms exit. It can be expected, however, that the most competitive farms remain, invest and improve their production efficiency. Hence, the production volumes have increased despite the decreased profitability of production, indicated by static farm level calculations (Ala-Mantila et al. 2000, p. 75). The extended model explains the increasing production volumes relatively well in the first years of the simulation.

The extended model brings more insight to the policy analysis compared to the base model. While the efficiency development in exogenous in the base model the efficiency development in the extended model reacts to changes in changing supports and profitability. Hence, the affects of Agenda 2000 on milk production until 2010 were found to be significantly larger when analysed using the extended model. Decreasing investments to efficient techniques due to decreased profitability because of Agenda 2000 result in a rapidly decreasing production in 2007-2010 when Agenda 2000 dairy reform is completed.

The depreciation rates were assumed the same in all techniques in the submodule of technology diffusion. This assumption can be easily relaxed if there is evidence and data concerning differing duration of the investment cycle of the alternative techniques. It turned out that the production levels are to some extent sensitive to the depreciation rate in the long term.

There are some disadvantages in the extended model, however, which require more careful analysis. The disadvantages relate to the aggregation of the production techniques and to the fixed input specifications of the alternative techniques. First, the efficiency of production is only related to the specified technology and farm size. Due to a low initial share of capital embodied in large dairy farms, the investments to large farms and efficient production systems increase very slowly in the first years of the simulation. High values of the η parameter are needed in order to replicate the actual dairy production levels in 1999. This, however, would mean that the number of large production units grew faster than is the case in reality.

It seems that the aggregate level development of production volumes are difficult to explain with a technology diffusion model with only three alternative techniques. There were only three major groups of dairy farms in the model. Thus the investments represent only the investments between those groups, not the investments in the farm groups. Significant economies of scale can be obtained when enlarging farms inside the specified farm categories.

More farm size groups could be added to the model in order to have a better coverage of the number of options farms have in their technology selection. Inclusion of many farm groups requires, however, many specifications of the production technology which need to be empirically validated as was done by Ala-Mantila (1998) for the technology specifications used in this application. When the number of farm groups is large the problem of aggregate constant technologies becomes less severe. Technologies would still be fixed by nature and there would be some continuous capital diffusion from some groups to other groups, which decreases the average cost of production.

One may also incorporate incremental improvements of each technology, i.e. gradual small improvements in the production technology due to the continuous efforts of farms to decrease the production costs. In terms of evolutionary economics, this is actually variety creation: farmers are able to find new ways to reduce the production costs without committing to heavy investments and shifting to other (already known) technologies. The counter-effect to this variety creation is selection: competitive pressures force the least performing farms to exit. The joint effect of variety creation and selection may considerably reduce the average production costs.

There are several ways to model incremental improvements. Because of learning and incremental improvements, the more a new relatively profitable technique is used the better it becomes (Silverberg, Dosi and Orsenigo 1988, Dosi, Marengo and Fagiolo 1996). Increased knowledge how to use the new production techniques efficiently is spilled over to other potential users as well. Hence, the learning processes and spill-over effects will magnify the path dependencies and self-inforcing patterns of the technology diffusion process. Such modelling techniques, which describe learning processes of farmers, for example, can be implemented with relatively little effort.

The problem with such modelling is, however, how to find empirical estimates of the necessary parameters. The propensity to invest in other techniques, the parameter η, was already an unknown parameter in the technology diffusion model. The parameter η, together with some plausible depreciation parameters, can be used for calibrating the capital levels in each farms groups in ex post period by comparing the model outcome to official structural statistics. The production volumes can then be calibrated by adjusting the parameters affecting the incremental improvements. The problem in such a calibration is, however, that there is little empirical information of such incremental improvements to which to compare the calibrated incremental improvements. In the worst case all random effects are assigned to the parameters of the equations representing incremental improvements. One also needs detailed information of each technology and the possibilities for incremental improvements in each farm size group.

What remains to be solved is how to model the selection of farms in each technology or a farm group. There is heterogeneity in the individual farm groups. There are significant differences in the production costs between farms of the same size (Riepponen 1998), and those farms with a low cost level are likely to remain in production. Hence, the average cost level decreases inside each farm group without any investments due to the selection of the farms. In the model, however, individual techniques are characterised by constant input use specifications.

In an ideal case one should model the distribution of the production costs in each farm group, and how the mean and variance of this distribution changes due to variety creation (like learning) and selection. Adding many farm size groups solves only partly the problem of selection: the capital in the least profitable techniques depreciates if the incremental improvements are not able to make the technique profitable. The problem how to model the exit of farms (probably with relatively high production costs) and thus the increase of the average profitability of farms in each farm size group remains to be solved.

11. Discussion

11.1. General remarks of the presented modelling framework

The basic problem in agricultural sector models has been the inadequate description of the agricultural production technology. There have been problems in explaining actual production and input use levels using static optimisation. Since the duration of agricultural investments is long, up to 30 years, it is obvious that the production response of farmers to exogenous shocks can be fully understood only in a dynamic model that takes into account fixed production factors.

If a static model is calibrated to observed ex post data (or to a set of single base year observations) by imposing sufficiently many arbitrary non-linear relationships between inputs and outputs (as is done in PMP approach, for example), one looses the information concerning ongoing adjustment processes and the actual causes and effects changing the agricultural technology. Such calibration can be done without any information of the actual production process and technology, and the age of the production equipment. Assuming the same fixed relationships, which happen to replicate the model to some ex post data, may result in very misleading results when evaluating medium- and long-term development of agriculture under different policy options. Imposing a large number of non-linear constraints in order to replicate the observed data may work in a short-term analysis in relatively stable conditions. Modelling technological change, however, is more involved, and requires understanding of the actual technological alternatives, investment behaviour of farmers and possible ways of making incremental improvements of the existing techniques.

Most optimisation approaches assume that profit maximisation is an adequate description of farmers' behaviour and that the production costs estimated are incomplete and insufficient. Hence, various calibration procedures are needed in order to replicate the base year production variables. This study joins the opposite view presented by Bauer (1988b), which assumes that data and production costs are correct, but static profit maximisation is not sufficient to explain the economic behaviour of farmers. Even if the methods used in this study and those of Bauer (1988b) are somewhat different, the basic way of model building is similar: first identify the relevant policy questions, outline the sector and policy systems, clarify the relevant economic linkages, and then build the specific system components and link them. Without trying to stay within in the domain of some single model type, several types and relevant approaches to specific problems can be used and combined. Sub-units can be changed (as happens in this study when exogenous efficiency development is replaced by the model of technology diffusion) if appropriate without the need to revise all other sub-units or the overall model structure. This kind of flexible framework makes it possible to test and experiment different behavioural rules, lags in production, and causal linkages.

This systems analysis approach should be seen as a global research plan. The specific sub-units in this modelling exercise need to be finalised and the available methodologies and experiences can be reviewed in a comprehensive manner. Continuous updating and revision is necessary. What is needed is additional empirical estimation of model parameters (like price elasticities of demand and substitution elasticities) and testing alternative assumptions and specifications in order to improve certain model components and the working of the overall system.

Dynamics is considered of primary importance in this study. Modelling technological change, both as a cause and effect of economic change, means the modelling of the actual dynamic and possibly path-dependent process of technological change: the investments in alternative techniques, as well as incremental improvements and variety creation of the existing techniques, and the selection process in the population of economic agents.

There is a long way to proceed, however, from the agricultural sector models presented in the literature to fully evolutionary models of technological change characterised by the features mentioned above. Also, DREMFIA model, even when embedded with the sub-model of technology diffusion, cannot be called an evolutionary, but a dynamic model. In building a dynamic model with regional dimension, embedded with five agricultural production lines, is a large project and not all problems can be found a unique and clear textbook solution. Some parts of the model need more careful estimation of the parameters, as discussed in Chapter 7. Some features of the model, like exogenous yields of sows, hens, and poultry animals, are still highly simplified. For example, the consumption of food items has been given exogenous trends and only little change (0.5-4%) is allowed from the given trend value. Consumption is mostly exogenous in the model. Consumer preference towards domestic products is modelled by setting the demand function of domestic products to a slightly higher level than the demand function of the imported products.

The supply side of the model, however, is rather detailed. The number of hectares of crops and the number of animals, as well as fertiliser use and feed use of animals, are endogenous in the model. The technology description is very detailed and input use is validated using empirical data. The list of inputs is comprehensive, as is the list of feed stuffs. Animal biology has been studied carefully and the appropriate energy, protein, and roughage requirements are included. Agricultural policy measures are modelled in great detail in all 14 regions in the model. Imported products are imperfect substitutes of the domestic ones (Armington assumption). Processing activities of 18 different dairy products have been included. Export products are assumed homogenous to the imported ones. There are export cost functions which prevent large annual fluctuations in exports, but still allows large changes in longer periods.

Altogether one can say that there are many features in the model which deminish or even eliminate some problems, like drastic supply response and excessive specialisation of production between regions, encountered in agricultural sector models based on optimisation, and capture many of the preferred features listed by Bauer (1988a, p. 18-20). Such features are detailed description of agricultural technology, possibility of technological change, possibility to incorporate hypotheses about farmers' behaviour, explicit dynamics, relations between consumer demand, food processing and agricultural production (especially in the dairy sector), and proper foreign trade specifications.

Keyzer (1988) gives guidelines for the specification of an agricultural supply module. Keyzer prefers optimisation frameworks to econometric ones and emphasises micro-economic requirements like concavity and monotonicity, as well as the representation of both crop yield and input requirements, and land allocation decisions separately. He also prefers maximum likelihood methods in parameter estimation and emphasises continuous response of the optimisation based supply modules. Keyzer does not mention dynamics and hence does not seem to consider dynamics of primary importance in supply moduls. However, the model presented in this study fits well the requirements proposed by Keyzer. For example, many non-linear relations in the model due to Armington assumption, endogenous feed use, and milk yield functions make the model to respond quite smoothly to exogenous changes.

One can also say that most of the objectives of the modelling exercise, as presented in Chapter 1, have been met. The full analysis of the effects of different investment aid programs (objective number 6), however, would require an extension of the technology diffusion model to all production lines. In this study, the model of technological diffusion has been constructed for dairy production only. The technical implementation of the technology diffusion model, however, facilitates a straight-forward inclusion of technological alternatives of other production lines as well. This inclusion, however, requires some additional data work, since full and detailed specification of production costs and use of different inputs have been calculated for a relatively small number of farm size groups (Ala-Mantila 1998). The number of technological choices, or farm size groups, in dairy production should also be increased in order to improve the working of the technology diffusion model. These tasks are quite straight-forward to complete, however.

An analysis made by means of the presented dynamic model is based on comparisons between the results of the so-called basic scenario (or "business as usual" -scenario) and alternative scenarios. One needs to compare the whole development path of the basic scenario with the development path of some alternative scenario. Different policies cause different dynamic patterns in production and its allocation between products and regions. This kind of analysis is not based on comparative statics, but on a kind of "comparative dynamics". The development paths represent the whole adjustment process to a given policy change. The series of short-term disequilibria may or may not converge to an equilibrium or to a stable development path.

The model should be used for comparing between different development paths, not primarily for predicting a single path. The final state of the simulation period represents one possible outcome of this dynamic process, and can be used as forecast only if all the assumptions can be considered "realistic". What are "realistic" assumptions to be used in forecasting is not always clear. In this study, the modelling effort is devoted to contribute to economic and policy analysis, not to build a pure forecasting model to be used in forecasting future values of stochastic variables. Forecasting leaves little work for economic analysis, which is of primary interest of this study.

This study presents two versions of the DREMFIA model: a *base model* with exogenous production efficiency development, and an *extended model* with a sub-module of endogenous development of production efficiency through a model of technology diffusion. Let us discuss the merits and disadvantages of the base model and the extended model in more detail.

11.2. Strengths and weaknesses of the base model

The starting point of this study was chosen after carefully evaluating the suitability of the different alternatives for the objectives (presented in Chapter 1). Recursive Programming (RP) with flexibility constraints was chosen as a methodological basis. Recursive programming (RP) models are vulnerable, however, since flexibility constraints may be seen merely as ad hoc measures to prevent "unrealistic" model outcomes. If the flexibility constraints are not estimated from real data, they may be claimed to be ad hoc and arbitrary, as well as the model outcome. This view, however, is challenged in this study. The RP approach was chosen because it is suitable for modelling a large economic system and provides a dynamic framework. It is also flexible and can be tailored for the special characteristics of Finnish agriculture.

There was a revolutionary change in agricultural policy in Finland in 1995. Estimating model parameters, such as flexibility constraints, using data from the old policy regime (before 1995), and using such estimates in providing future policy response, is not seen as a plausible procedure in this study. A rapid structural adjustment is in progress in Finnish agriculture and many changes (like those in imports and food consumption) have taken place at the same time. Hence, it is problematic to base parameter estimates on data of some particular years which do not represent an economic equilibrium in agriculture. This makes it difficult to build a sector-level model and to perform a sector level analysis. When the adjustment process and the joint actions of farmers under many constraints are to be modelled, many simplifications and assumptions have to be made.

Specific emphasis has been given to the plausibility and interpretation of the flexibility constraints in this study. A closer investigation of the actual production process of agriculture reveals that farmers are very much tied to the earlier production decisions in the short term. The possibilities to changes in the short term vary across the production lines. One can find clear reasons for the frictions which prevent short-term changes. Lifetime of cattle animals, for example, is longer than that of pigs or poultry, for example. Hence, the number of animals can be more easily changed in pig and poultry husbandry in the short term than in dairy production, where the number of animals is tied to the production decisions of the last three years. Thus the flexibility constraints cannot be termed fully arbitrary. On a sector level, however, there is some uncertainty relating to the values of flexibility constraints, even if one can compare the chosen values with the maximum or minimum annual changes to those in official statistics.

Instead of relying on econometric estimates of the flexibility constraints, an explicit sensitivity analysis on model parameters may provide more valuable insight to the adjustment process of agriculture. Such a sensitivity analysis showed strong results. In some cases, like in the case of agricultural income, the results were robust even when extending the flexibility constraints of production variables by 100%. In some few cases, however, the results were sensitive on the flexibility constraints. The area under set-aside, representing the only alternative use of land in the model, appeared to be sensitive on the flexibility constraints. If the area under set-aside was allowed to vary 40-60% annually the areas under set-aside increased quite quickly and crop production volumes were significantly lower compared to cases where the area under set-aside was allowed to change 20-30% annually. Large fluctuations in set-aside areas are unlikely, however, since the annual changes in areas under set-aside have been 3-30% in recent years. The large range of change given for the set-aside area represents an extreme case of unprofitable crop production where the opportunity cost of crop production becomes of great importance.

The flexibility constraints given for the production variables can be considered as strict technical and biological constraints reducing the feasible region of optimisation, but also as behavioural constraints. The flexibility constraints represent the ability and possibilities of farmers to optimise. Farmers' production decisions may be based not only on profit maximisation, but also on other arguments, like life style issues and environmental values. The optimising behaviour is also dependent on farmer's skills and the possibilities for employment outside agriculture. The economic situation in the farm family household may also influence farmers' optimising behaviour. For this reason, it is appropriate to evaluate the effects of policy changes at different levels of optimising behaviour of farmers. If any robust results can be derived, it shows that the policy effects themselves are quite robust, i.e. farmers can achieve relatively little when performing explicit optimisation. Instead, if incomes and production quantities are sensitive to the optimising behaviour, farmers may gain considerably by better planning and optimisation.

Since the actual optimising behaviour of farmers is uncertain, some expected policy effects are uncertain, too. If the policy effects are sensitive on certain behavioural assumptions, like the extent of profit maximisation, policy makers should be made aware of this. This kind of sensitivity analysis is often lacking from some neo-classical models, like static agricultural sector models, assuming immediate and full optimisation of all economic agents. If the relevant farm-level constraints and dynamics are not taken into account, the results may lead to misleading conclusions.

The results of the base model challenge the view that the outcomes of RP models are totally determined by "arbitrary" flexibility constraints and thus the RP approach can provide no information on the policy impacts. Such a view is based on a belief that everything can and should be estimated using statistical methods, and using the statistical estimates together with immediate and full optimisation is the only reliable way of making economic and policy analysis. In this study, however, such a view is challenged. Changes in production processes and policy are gradual because of a number of reasons. A dynamic framework is needed where the adjustments, made in order to maximise profits, are incomplete in the short term. Various exogenous changes during the adjustment process may change the course of action of economic agents. At any given moment, the actual situation in reality may not correspond to an economic equilibrium. If great changes take place in the economic environment, as happened in Finnish agriculture in 1995, the view of agricultural adjustment as a dis-equilibrium process is indispensable if the model outcome is to be close to the reality and if the results of the analysis are to be of practical relevance to policy makers.

The above statement does not mean that econometric estimates should always be neglected. On the contrary, it is seen in this study that econometric estimates are needed and they should be computed if possible. One should carefully evaluate, however, what the reliability of the parameter estimates is, what they represent, and how they affect the model outcome. For example, estimates of price elasticities of demand may vary if different lengths of time series are used in the estimation, and positive price elasticities of demand are unacceptable if consumer surplus is to be calculated. Despite the possible problems in estimation, parameter estimates are needed in order to deminish the number of parameters to be varied in the sensitivity analysis.

The base model assumes exogenous efficiency development, i.e. labour and capital inputs needed per hectare and animal, in agriculture. A major part of productivity growth is also exogenous. The milk yield per dairy cow is made endogenous by a response function which determines the milk yield as a function of feed use. An annual increase in the scalar parameter of the milk yield function is exogenous representing the increasing genetic production potential which is largely independent of agricultural policy in the short and medium term. The work performed by biological research most often influences the actual production only after many years. Hence, the yield potential of dairy cows were assumed to be independent of the policy. Price changes, however, affect the feeding of dairy cows and the milk yields in the model. The yields of sows, hens and poultry animals are exogenous since there was no proper data or easy ways for constructing yield functions.

There is scope for a model with exogenous technical change since the agricultural investments in Finland can be effectively steered by the investment aid system. One can make explicit scenario analysis and policy analysis with varying degrees of technical change. Since the investment decisions of farmers are highly dependent on the investment aid level, the investments are not likely to be very different under different policy scenarios with slightly different product prices, direct payments and profitability. Using a model with exogenous technical change one may analyse the possible level of production and income in different parts of the country at a given level of efficiency development. One may also evaluate what is the rate of efficiency and productivity development needed in order to sustain the current level of production and agricultural income at given alternative policies.

While exogenous technical change is appropriate when evaluating different scenarios of technical change, it can also be considered a weakness of the base model if the same assumptions are used in very different policy scenarios. Different policy scenarios imply different profitability which, despite the investment aids, influences investments and sunk costs. The actual investment decisions are always made by individual farmers and the technological choices can be considered endogenous despite the fact that investments are heavily dependent on the investment aid. Hence, the policy scenarios to be analysed using the base model should not be very different and the application area of the base model is quite limited. If a large range of policy options are to be evaluated, investments and sunk cost behaviour need to be modelled explicitly.

In the base model there are assumptions concerning sunk costs which include the investment aid. Investment aid is paid for agriculture in order to increase production efficiency. One weakness of the base model is the calibration of the production variables close to ex post data using sunk costs. As discussed in Chapter 9, such an approach is problematic especially in the case of pork and poultry meat production, which are characterised by large fluctuations of product prices. The actual production levels of pork and poultry meat in the ex post period 1995-1999 could be achieved only by making major adjustments in the level of sunk costs. This kind of calibration is problematic, since only the last observations of the production volume and prices determine the level of sunk costs. There may also be some random factors not observed in the official statistics, like temporary problems with animal diseases which affect production. Hence, the sunk costs used in calibration may not represent the actual sunk costs.

Decreasing the level of sunk cost from the high level of 1998-1999 gradually to the level of investment aid until 2010, however, implies rational economic behaviour: all fixed costs have to be covered in the long term, even if in the ex post period they are obviously not covered. Using the specification of sunk cost and the assumption of rationality of farmers yields clear and logical policy conclusion in the analysis of Agenda 2000: The reform result in higher production volumes and income in northern support areas, but in lower production volumes and income in the southern support areas, compared to the 1999 policy.

11.3. Strengths and weaknesses of the extended model

In the investment aid system it is only required that the investing firm must be large enough, but no strict regulations on the individual technological alternative are given. Since there are alternative technological choices different from the dominant techniques available for farmers, there is a scope for the extended model which describes endogenous technological choices and the adoption of the alternative technologies. In the extended model, the technology diffusion model suggested by Soete and Turner (1984) is used in modelling investments and technical change.

In the extended model the investments and efficiency development of agricultural production are strongly influenced by profitability and thus the policy variables, not by exogenous efficiency development which is assumed to be the same in all policy scenarios, as is the case in the base model. Investment function 6.57 (presented in Chapter 6) assumes rational profit maximising behaviour of farmers. The capital stock in each technique may increase only if the production using the technique generates a sufficient rate of return on capital (compared to the rate of return of other techniques, and the interest rate in the general economy).

The model of technology diffusion takes into account the fact that all farmers do not shift to the best performing technique immediately. Investments to different production techniques depend not only on the profitability but also on the level of information farmers have about the technique, and farmers' capability to learn and adopt the technique. There are also various other frictions, like profitability of the farm, land and capital availability, the age of the production equipment and the farmer, preventing farmers from adopting the best technique immediately. The level of information of each technique is assumed to depend on the spread of each technique. This, in turn, may result in path-dependent and self-inforcing patterns of technical change. The extended model with endogenous investments and technology diffusion provides S-shaped penetration curves of the new techniques. The S-shaped form is often encountered in empirical research of technological change.

Including only three alternative farm size groups with different production technology was not sufficient when trying to calibrate the production volumes exactly to the ex post levels. Since the investments and technical change inside the farm size groups were neglected, unrealistically high capital shifts between the three techniques, when compared to the actual shifts of capital between the three farm size groups, were needed in order to reach the actual production volumes in 1998-1999. Hence, more techniques and farm size groups should be added to the model.

In addition, one may incorporate incremental improvements in each technique. Some learning models could be used in modelling such incremental improvements as a function of economic incentives. Such modelling would bring the model closer to the evolutionary economics paradigm, since learning actually means variety creation in different farm size classes. The parameters of the incremental improvement function could be used in model calibration, while the parameter representing the capital shifts can be set in order to replicate the actual structural development in the ex post period.

What remains to be solved in the model of technology diffusion is how to model the selection of farms in each farm group. In an ideal case one should model the distribution of the production costs in each farm group, and how the mean and variance of this distribution changes due to variety creation and selection. Adding many farm size groups into the model solves partly the problem of selection: the capital in the least profitable techniques depreciates if the incremental improvements are not able to make the techniques profitable. The question how to model the exit of farms (with probably relatively high production costs) and thus the increase of the average profitability of farms in each farm size group – without any investments in the group – remains to be solved.

The technology diffusion model does not eliminate all flexibility constraints which are still needed for feeding variables and areas of different crops. Technological choices in crop production can be modelled as technological diffusion, but the flexibility constraints cannot be eliminated since the capital employed in production equipment cannot be assigned to the production activities of individual crops. Areas of some crops and the amount of some feed stuffs in the animals diets can be varied more flexibly than the capital in different production techniques.

11.4. Other suggestions for model improvement

Only process-level technical change is included in the model of technology diffusion, but product-level technical change is excluded. One example of a product-level technical change is organic production. There is little organic production in Finland. 6% of the total field area was under organic cultivation in 1999 (Luomuliitto 2000). Since crop yields are low in organic production the total crop production volume, however, is low. There is very little organic production of animal products in Finland. For example, less than 0.5% of pork production was organic in 1999 (Peltomäki 2000). However, organic production is becoming gradually a more popular choice for farmers.

The problem in modelling organic production is how to model the substitution between organic products, conventional domestic products, conventional imported products, and imported organic products. One needs a large set of substitution elasticities in a model which includes all these products as imperfect substitutes. However, the simple Armington demand system used in this study, including only two substitutes of the same product, breaks down when more than two imperfect substitutes are included. Hence, one needs to replace the two-product Armington demand system with one which allows many imperfect substitutes, i.e. types of the same base product. Such systems where each product has many origins, and where all products from all origins may substitute one another, are employed in international trade models which work at the level of the whole national economy (Shoven and Whalley 1992, p. 205-207).

Different products, like pork and beef, are not imperfect substitutes in the model, but the consumption of each meat category, for example, may change freely and independently within the given narrow bounds for consumption. Hence, within the very narrow bounds different products may perfectly substitute each other. An ideal solution would be to make all products imperfect substitutes. The consumption of food items in Finland is quite unresponsive, with few exceptions, to price changes (MTTL 2000, p. 43-44), and relatively little substitution occurs even in the case of large price changes. It seems that there are persistent trends due to life style changes and other factors which affect consumer behaviour more than small or even moderate price changes. Hence neglecting the substitution between different food items is not of crucial importance in making agricultural policy analysis, and the inclusion of such substitution reactions would result in only a minor improvement of the model.

Substitution at different levels (i.e. between different commodities, like pork and beef, and between different product types, i.e. between domestic conventional produced pork, imported conventional produced pork, domestic organic pork, and imported organic pork) can be modelled using nested utility functions (Shoven and Whalley 1992, 205). A number of different functional forms of such functions, such as CES (Constant Elasticity of Substitution), are used in general equilibrium models and in trade models. Inclusion of a wider range of products and product types and substitution reactions is relatively straightforward technically. The estimation of a large number of substitution elasticities, however, may be difficult due to lack of data, and require a lot of work.

Land allocation in the model is influenced by the regional crop yields acquired from the statistics. If great changes occur in regional crop areas, however, the average regional yield levels may change, since land is not homogenous in quality. To be able to fully account for the differences in land quality, one should include information of the distribution of the land quality over the total arable area in each region. In including such information in the model land needs to be divided in land types in all regions with distinct yield levels for each crop. Furthermore, the fertiliser response function of each crop may be different in each land type. Inclusion of different land types would bring the supply response of the model closer to reality in the case of large changes in crop areas. Furthermore, environmental indicators could be calculated separately in each land type which would be of great help in evaluating environmental effects of agricultural policies. Including information of different land types is a large project and could be a topic of further research.

Summary and conclusions

This study is about constructing a dynamic regional sector model for Finnish agriculture (DREMFIA) to be used in economic and policy analysis. The model should provide information on the effects of different agricultural policies on production volumes and agricultural income in different regions in Finland in order to help agricultural economists in their research and policy makers in estimating the effects of different policy decisions. Information about environmental effects of agricultural policies is also expected from the model.

The economic environment of Finnish agriculture experienced a fundamental change when Finland joined the EU in 1995. The national agricultural policy characterised by high producer prices was replaced by the Common Agricultural Policy (CAP) of the EU characterised by low producer prices and high direct payments paid per hectare and animal. Further changes in prices and support have taken place in the so-called transitional period in 1995-1999. Agenda 2000 agricultural reform brings other changes in 2000-2007. Further changes in CAP are already under speculation.

Since agriculture is characterised by the long duration of investments, the adjustment to the policy changes is likely to take a long time. Investment aid is granted for Finnish farmers in order to foster structural development. No instant economic equilibrium can be reasonably assumed in Finnish agriculture in the given policy context. For this reason, a dynamic model representing the actual adjustment process in a dis-equilibrium setting has been constructed in this study. The methodologies used in this study have been selected (Chapter 4) after carefully evaluating the relevant alternatives (Chapter 3). Since ready-made modelling templates satisfying all the objectives of this study could not be found, the appropriate model was built after reviewing a large set of alternative methodologies.

It is concluded in Chapter 4 that optimisation framework is appropriate in this modelling exercise. The large number of products, regions and other dimensions and various constraints was considered more difficult to be modelled in the econometric approach than in the optimisation approach. Internal material flows (like crop used in feeding cattle), representation of multiple input technology, some policy measures directly linked to physical production factors, like physical production quotas, base area of CAP support, as well as set-aside rates, can be best modelled in optimisation framework. Given the large number of products, regions and balance constraints imposed on the commodities, the essence of technological and structural change, and detailed and consistent description of many policy measures, the optimisation approach is an obvious choice.

The theoretical basis of the DREMFIA model is presented and discussed in Chapter 5. It turns out that dis-equilibrium dynamics is not a new concept but a framework discussed by economists longer than 100 years. In fact, many outstanding economists have expressed their preference for dynamic and evolutionary conceptions over the static equilibrium conceptions. There have been relatively few numerical applications of large dynamic models, however, since it has been feared that such models would be too complex and intractable. Since the 1980s, however, the tool kit of modellers is sufficiently rich for building complex dynamic models.

A recursive optimisation model is constructed in this study which does not assume instantaneous adjustment but represents an adjustment process in dis-equilibrium (Chapter 6). This study presents two versions of the DREMFIA model: *base model* with exogenous production efficiency development, and *extended model* with a sub-module of endogenous development of production efficiency through a model of technology diffusion.

Domestic and imported products are imperfect substitutes in the model. Consumer preference towards domestic products is modelled by setting the demand functions of domestic products to a higher level than the demand function of the imported products. The aggregate consumption of both domestic and imported products, however, may change only little from the given trend values.

The supply side of the model is rather detailed. The number of hectares of crops and the number of animals, as well as fertiliser use and feed use of animals, are endogenous in the model. The list of production inputs is comprehensive, as is the list of feedstuffs. Animal biology has been taken into account in the model and the appropriate energy, protein, and roughage requirements are included. Empirically validated production functions, however, are used in determining the response of crop yields to fertilisation and milk yields of dairy cows on feed use. Agricultural policy measures are modelled in great detail in all 14 production regions in the model. Processing activities of 18 different dairy products have been included. Export products are assumed homogenous to the imported ones. There are export cost functions which prevent large annual fluctuations in exports, but still allow major changes in longer periods.

Flexibility constraints are used in constraining the production variables, like the number of animals, hectares of different crops, and feeding variables representing animal diets, to the values of the production variables of the previous year. The use of flexibility constraints is motivated by the biological and technical restrictions at the farm level which prevent instantaneous adjustment. The chosen flexibility constraints can be compared to the actual changes in the production variables in recent years, but estimation of the flexibility constraints using data from the old policy regime (before 1995), and using such estimates in providing future policy response, is not seen as a plausible procedure in this study. Changes in production variables in the old policy regime, characterised by relatively stable conditions, should not determine the changes in production variables in the current conditions.

Even if one can find quite clear biological and technical constraints for the production variables, there is some uncertainty concerning the exact magnitudes of the flexibility constraints. The flexibility constraints may also include risk averse behaviour of farmers, or other frictions affecting the supply response. Hence, the flexibility constraints can be understood as behavioural parameters as well. For this reason, a comprehensive sensitivity analysis was performed in order to check the effect of the flexibility constraints on the model outcome representing agricultural production and income. It turned out that the model outcome, especially the agricultural income, is quite robust on the magnitude of the flexibility constraints. There were also relatively small differences in the production volumes of most agricultural products over time when using different flexibility constraints. This is understandable, since there are many non-linear relations in the model, like imperfect substitution between imports and domestic production, as well as endogenous feeding variables, and milk yield function.

The flexibility constraints rarely become binding in animal production, but are more often binding in crop production. The robust results in animal production are also explained by the fact that when more space is given for the production variables they partially cancel each out: more flexible feed use, for example, make animal production more profitable and thus the number of animals does not decrease at maximum speed as it does in the case when the rate of change in feeding variables and in the number of animal is made smaller. The varying directions of change at consecutive years often make the development paths of agricultural production and income quite similar over time without large differences, even if varying values for the flexibility constraints are used.

One conclusion to be made from the sensitivity analysis is that in some cases farmers gain relatively little by more careful optimisation and by making greater changes in the production variables. In some other cases, however, farmers may gain substantial economic benefits when explicitly optimising within a feasible range of each production variable. A strong and robust result from the sensitivity analysis is that Agenda 2000 reform, together with the related domestic policy decisions, results in higher agricultural production and income in northern support areas (C-areas), but in a lower production and income in Southern Finland (A and B -areas), even at a relatively rapid development of production efficiency.

The base model assumes exogenous efficiency development, i.e. labour and capital inputs needed per hectare and animal, in agriculture. Exogenous technical change is a plausible assumption when making explicit scenario analysis with varying degrees of technical change. In the Finnish agriculture technical change is largely a policy variable because of the publicly financed and controlled investment aid system. There is a scope for a model with exogenous technical change since the agricultural investments in Finland can be effectively steered by the investment aid system. Using a model with exogenous technical change one may also analyse the possible level of production and income in different production lines and in different parts of the country at a given level of efficiency development. One may also evaluate what is the rate of efficiency and productivity development needed in order to sustain the current level of production and agricultural income at given alternative policies.

The policy scenarios to be analysed using the base model should not be very different and thus the application area of the base model is rather limited. If a large set of policy options are to be evaluated, the same exogenous technical change in all policy scenarios is not a realistic assumption, but the investments should be modelled explicitly. In the *extended* model with endogenous technology diffusion the investments and efficiency development of agricultural production are strongly influenced by profitability and thus by the policy variables. Hence, as expected, the effects of Agenda 2000 on production are greater if the extended model with endogenous investments is used instead of the base model with exogenous efficiency development. In the long term, in particular, the accumulated capital in different production techniques and the resulting production efficiency development is strongly dependent on agricultural supports.

The technology diffusion model assumes rational profit maximising behaviour of farmers. The capital stock in each technique can only increase if the production using the technique is still profitable after all fixed costs. The model of technology diffusion assumes that all farmers do not shift to the best performing technique immediately. The extended model takes into account imperfect information and heterogeneity of economic agents and provides with S-shaped penetration curves of the new alternative techniques. This is desirable since the S-shaped form is often encountered in empirical research of technological change.

The flexibility constraints concerning the upper bounds of the number of animals were made endogenous in the extended model. This was possible since the capital employed in each production technique, and hence the number of animal places available, is endogenous in the extended model.

Including only three alternative farm size groups with different production technologies, however, was not sufficient in calibrating the production volumes exactly to the ex post levels. Since the investments and technical change inside the farm size groups were neglected, unrealistically high capital shifts between the three techniques, compared to the actual shifts of capital between the three farm size groups, were needed in order to reach the actual production volumes in 1999-2000. Hence, more techniques and farm size groups should be added to the model. Some learning models could also be used in modelling incremental improvements as a function of economic incentives in the extended model.

There are some parameters, like the substitution elasticities between domestic and imported products, in the model which are difficult to estimate due to data and other problems. This is why the DREMFIA model should be used in policy analysis, i.e. in comparing the effects of different policy scenarios, not primarily in forecasting future values of production variables. The use of extensive statistical data and various sources of technical and biological data may shrink substantially the number of parameter values to be varied in the sensitivity analysis. Sensitivity analysis should not be overlooked, however, especially when performed on behavioural parameters of the model, since it can provide valuable insights both for policy makers and for the economic interest groups themselves.

This study contributes by presenting one alternative for static and moving equilibrium models. Dynamic models, and models of sector level investments, in particular, are relatively scarce in the literature of agricultural sector models. Popularity of static modelling exercises may result from a lack of dynamic modelling alternatives. If the dynamics and gradual changes in policy and technology are parts of the reality, however, they should be modelled explicitly, as was attempted in this modelling exercise. Development of dynamic methods to be used with reasonable effort in empirical research, like in agricultural sector modelling, is needed.

A major contribution of this study is to select the appropriate methodology and to combine the relevant approaches into a large dynamic model whose parts are consistent with each other. Modelling an interplay of technical and economic change in a dynamic context is likely to result in large and complex models. This study shows, however, that it is possible to analyse large economic systems by using a large dynamic model without making the model too complex for empirical work. The results are understandable and follow economic logic, but they are not too abstract from reality to conduct empirical analysis.

References

Aaltonen, J., Järvenpää, M., Klemola, E., Laurila, I.P. 1999. Viljan korjuu-, kuivaus- ja logistiikkakustannukset Suomessa (Harvesting, drying and logistics costs of cereals in Finland). In Finnish, an English Abstract. Agricultural Economics Research Institute, Helsinki, Finland. Working papers 2/1999. 22 p.

Agra Europe 1999a. Enlargement poser for EU dairy policy. P. A/1-A/3. November 19, 1999.

Agra Europe 1999b. Berlin fudge causing dairy sector headaches. P. EP/7. November 19, 1999.

Agra Europe 1999c. Agenda 2000 not enough to beat URA limits. P. A/3. December 23, 1999.

Agra Europe 2001. Impact of dairy policy change post-2006. P. A/1-A/3. January 12, 2001.

Ala-Mantila, O. 1998. Maataloustuotteiden tuotantokustannukset viljelmämalleilla (The production costs of agricultural products according to farm models). In Finnish, an english abstract. Agricultural Economics Research Institute. Research Reports 222. Helsinki. 6-93 p.

Ala-Mantila, O., Lehtonen, H., Aakkula, J., Knaapinen, P., Laurila I.P. & Niemi, J. 2000. The effects of Agenda 2000 on Finnish agriculture. Agricultural Economics Research Institute, Finland. Research Publications 244. Helsinki. p. 7-93.

Andersen, E. 1994. Evolutionary Economics. Post-Schumpeterian Contributions. Pinter Publishers. 238 p.

Apland, J. & Jonasson, L. 1992. The conceptual backround and structure of SASM: A Swedish agricultural sector model. Swedish university of agricultural sciences, Uppsala. 32 p.

Apland, J., Öhlmer, B. & Jonasson, L. 1994. Sector modeling for prediction and evaluation. A useful tool for interdisciplinary research. Swedish Journal of Agricultural Research 24: 119-130.

Babcock, B.A. 1999. Conflict between Theory and Practice in Production Economics: Discussion. American Journal of Agricultural Economics, Vol. 81, No. 3 (August 1999) 719-721.

Banse, M. & Tangermann, S. 1996. Agricultural implications of Hungary's Accession to the EU – Partial versus general equilibrium effects. Paper presented in the 50th EAAE Seminar "Economic Transition and the Greening of Policies: New Challenges for Agriculture and Agribusiness in Europe", Giessen, Germany, October 15-17 1996. 15 p.

Bauer, S. 1988a. Historical review, experiences and perspectives in sector modelling. Proceedings of the 16th symposium of the European Association of Agricultural Economists, April 14th-15th, 1988. p. 3-22.

Bauer, S. 1988b. Some lessons from the dynamic analysis and prognosis system (DAPS). Proceedings of the 16th symposium of the European Association of Agricultural Economists, April 14th-15th, 1988. p. 325-344.

Bauer, S. & Kasnakoglu, H. 1990. Non-linear programming models for sector and policy analysis. Experiences with the Turkish agricultural sector model. Economic Modelling, July 1990. p. 275-290.

Baumol, W.J. 1977. Economic theory and operations analysis. Prentice Hall. 695 p.

BoF 2000. Statistical Figures of Bank of Finland. http://www.bof.fi/fin/tilastot.

Bradford, G. 1987. An opportunity cost view of fixed asset theory and the overproduction trap: Comment. American Journal of Agricultural Economics, May 1987. p. 392-394.

Brockmeier, M., Hertel, T. & Swaminathan, P. 1996. Integration of the central European economies into the European Union. Paper presented at the GTAP Follow-Up/50th EAAE Conference, Giessesn, Germany, October 15-17 1996. 39 p.

Brooke, A., Kendrick, D. & Meeraus, A. 1992. GAMS. A user's guide. Release 2.25. The International bank for Reconstruction and Development. The World Bank. 278 p.

Buhr, B.L. & Kim, H. 1997. Dynamic Adjustment in Vertically Linked Markets: The Case of US Beef Industry. American Journal of Agricultural Economics, Vol. 79, No. 1 (February 1997): 126-138.

Bäckman, S., Vermeulen, S. & Taavitsainen, V-M. 1997. Long-term fertilizer field trials: Comparison of three mathematical response models. Agric. Sci. Finl. Vol. 6:151-160.

Chavas, J-P. 1994. Production and Investments Decisions Under Sunk Cost and Temporal Uncertainty. American Journal of Agricultural Economics 76 (February 1994), p. 114-127.

Day, R.H. 1975. Adaptive Processes and Economic Theory. In: Day, R.H. & Groves, T. (eds.). Adaptive Economic Models. Proceedings of a Symposium conducted by the Mathematics Research Center, The University of Wisconsin-Madison, October 21-23, 1974. Academic Press. 581 p.

Day, R.H. 1978a. Notes on adaptive economic theory. European Review of Agricultural Economics 3(2/3) p. 235-264.

Day, R.H. 1978b. Some adaptive models. European Review of Agricultural Economics 3(2/3) p. 323-348.

Day, R.H. 1994. Complex Economic Dynamics. Volume 1: An introduction to Dynamical Systems and Market Mechanisms. The MIT Press 1994. 309 p.

Day, R.H. & Chen, P. (eds.). 1993. Nonlinear Dynamics and Evolutionary Economics. Oxford University Press. 335 p.

Day, R.H. & Cigno, A. 1978. Modelling Economic Change: The Recursive Programming Approach. North Holland. 447 p.

Day, R.H. & Groves, T. (eds.). 1975. Adaptive Economic Models. Proceedings of a Symposium conducted by the Mathematics Research Center, The University of Wisconsin-Madison, October 21-23, 1974. Academic Press. 581 p.

Day, R.H. & Pingle, M. 1996. Modes of economising behaviour: Experimental evidence. Journal of Economic Behaviour and Organisation Vol. 29 (1996), p. 191-209.

Dixit, A. 1988. Optimal Trade and Industrial Policies for the US Automobile Industry. In: Roger C. Feenstra (ed.). Empirical Methods for International Trade. Massachusetts Institute of Technology. p. 141-165.

Dixit, A.K. & Pindyck, R.S. 1994. Investment under Uncertainty. Princeton University Press. 468 p.

Dosi, G., Marengo, L., Fagiolo, G. 1996. Learning in Evolutionary Environments. IIASA working paper WP-96-124, november 1996. International Institute for Applied systems Analysis, Laxenburg, Austria. 66 p.

Dosi, G. & Nelson, R.R. 1994. An introduction to evolutionary theories in economics. Journal of Evolutionary Economics 4: 153-172.

European Commission 1997. The Agricultural Situation in the European Union. 1996 Report. Brussels and Luxembourg. 156 p. + statistical tables 345 p.

European Comission 1999a. Farm Structure. 1995 survey: main results. European Communities, Luxembourg. 147 p.

European Comission 1999b. Agenda 2000 : For a stronger and wider Union. http://europa.eu.int/scadplus/leg/en/s60000.htm

European Comission 1999c. Reform of the Common Agricultural Policy. Support for rural development. http://europa.eu.int/scadplus/leg/en/lvb/l60006.htm.

European Commission 1999d. Agenda 2000. Reform of the common agricultural policy (CAP). http://europa.eu.int/scadplus/leg/en/lvb/l60002.htm.

Finfood 1999. Available (in Finnish): http://www.finfood.fi/finfood/luomu.nsf/pages/index.htm.

Fusfield, D.R. 1996. Rationality and economic behaviour. Journal of Economic Methodology 3: 2, 307-315.

Greene, W.J. 1999. Econometric Analysis, 4th ed. New Jersey: Prentice Hall. 1004 p.

Hagedoorn, J. 1989. The Dynamic Analysis of Innovation and Diffusion. Pinter Publishers. 197 p.

Hall, P. 1994. Innovation, Economics and Evolution. Harvester Wheatsheaf. 418 p.

Hanf, C-F. 1988. Research organisation and co-operation in the field of agricultural sector modelling. Proceedings of the 16th Symposium of the European Association of Agricultural Economists, April 14th-15th, 1988. p. 355-358.

Hanley, N. & Spash, C.L. 1993. Cost-Benefit Analysis and the Environment. Edward Elgar Publishing Ltd. 278 p.

Hansson, B.A. 1982. The Stockholm School and the Development of Dynamic Method. Croom Helm Lim. Great Britain. 286 p.

Hart, N. 1996. Equilibrium and time: Marshall's dilemma. Journal of Economic Methodology 3:2, 285-306.

Hazell, P.B.R. & Norton, R.G. 1986. Mathematical Programming for Economic Analysis in Agriculture. Macmillan publishing company, New York. 400 p.

Heckelei, T. & Britz, W. 1999. Maximum Entropy Specification of PMP in CAPRI. Capri working paper 99-08. Institute for Agricultural Policy, University of Bonn. 22 p. Available in http://a16.agp.uni-bonn.de:80/agpo/rsrch/capri/wrkpap_e.htm.

Heckelei, T. & Britz, W. 2000. Concept and Explorative Application of an EU-wide Regional Agricultural Sector Model (CAPRI project). Paper presented in 65th EAAE Seminar "Agricultural Sector Modelling and Policy Information Systems", Bonn, Germany March 29-31, 2000

Heckelei, T., Witzke, P. & Henrichsmeyer, W. 2001. Agricultural Sector Modelling and Policy Information Systems. Proceedings of the 65th European Seminar of the European Association of the Agricultural Economics (EAAE), March 29-31, Bonn, Germany. Wissenschaftsverlag Kiel KG. 321 p.

Heikkilä, T. 1980. Typpilannoitteiden taloudellisesta käytöstä koetulosten perusteella (in Finnish, no English abstract). Agricultural Economics Research Institute, Helsinki, Finland. Research Reports 70. 45 p.

Hertel, T.W. (ed.). 1997. Global Trade Analysis: Modeling and Applications. Cambridge University Press. http://www.agecon.purdue.edu/gtap/model/index.htm.

Hirvonen, A. 2000. Agricultural total calculations 1992-1999. Agricultural economics Research Insitute, Helsinki, Finland. Research Reports 244. p. 105-148.

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

Hsu, S-H. & Chang, C-C. 1990. An adjustment-cost rationalisation of asset fixity theory. American Journal of Agricultural Economics, May 1990, p. 298-308.

Hubbard, L.J. 1995. General equilibrium analysis of the CAP using the GTAP model. Oxford Agrarian Studies Vol. 23, No. 2: 163-176.

Jensen, J.D. 1996. An pplied econometric sector model for danish agriculture (ESMERALDA). Statens jordbrugs- og fiskeriökonomiske institut. Rapport nr. 90. 121 p. Copenhagen.

Johansson, P.O. 1991. An introduction to modern welfare economics. Cambridge University Press. 176 p.

Johnson, G.L. 1982. An opportunity cost view of asset fixity theory and the overproduction trap: Comment. American Journal of Agricultural Economics, November 1982, p. 773-775.

Johnson, M.A. & Pasour, E.C. jr. 1981. An opportunity cost view of fixed asset theory and the overproduction trap. American Journal of Agricultural Economics, February 1981, p. 1-7.

Jonasson, L. & Apland, J. 1997. Frontier technology and inefficiencies in programming sector models: An application of Swedish agriculture. European Review of Agricultural Economics 24: 031-046.

Just, R.E. & Pope, R.D. 1999. Implications of Heterogeneity for theory and Practice in Production Economics. American Journal of Agricultural Economics, Vol 81, No. 3 (August 1999): 711-718.

Kallinen, A. 2000. Lopettamismyrsky sikatiloilla laantuu. Lihatalous 7/2000. Publisher: Lihatalouden keskusliitto. p. 44-45.

Karshenas, M. & Stoneman, P. 1995. Technological Diffusion. In: Stoneman, P. (ed.). Handbook of the Economics of Innovation and Technological Change. p. 265-297.

Kasnakoglu, H. 1988. Data Requirements and Evaluation. Proceedings of the 16th Symposium of the European Association of Agricultural Economists, April 14th-15th, 1988. p. 347-348.

Kettunen, L. 1981. Maataloussektorin suunnittelu- ja ennustemalli Massu. Ensimmäinen versio. Maatalouden taloudellisen tutkimuslaitoksen tiedonantoja nro 84. Helsinki. 45 s.

Kettunen, L. 1992. Agricultural policy in Finland (in Finnish). Agricultural Economics Research Institute, Finland. Research Reports 185. Helsinki 1992. 148 p.

Kettunen, L. 1995. Finnish Agriculture in 1994. Agricultural Economics Research Institute, Finland. Publications 76a. 63 p.

Kettunen, L. 1996. Finnish Agriculture in 1995. Agricultural Economics Research Institute, Finland. Publications 79a. 61 p.

Keyzer, M. 1988. Some views on agricultural sector modelling. Proceedings of the 16th symposium of the European Association of Agricultural Economists, April 14th-15th, 1988. p. 23-30.

Kirman, A. 1992. Whom and what does the representative individual represent? Journal of Economic Perspectives 6, No. 2, p. 117-136.

Kleemola, H.M. 1989. Säilörehun typpilannoituksen kannattavuus. Maanviljelystalouden tutkielma. Helsingin yliopiston maatalousekonomian laitos.

KM 5/2000. Ruokintaan uusia suuntia. Käytännön maamies.

Lankoski, J. & Lehtonen, H. 1998. Agricultural policy reforms and environmental quality in Finland: A sector model application. Agricultural Economics Research Institute. Research reports 225. Helsinki. p. 32-52.

Laurinen, H. 1996. Elintarikkeiden hintamarginaalit vuosina 1985-1996 (The marketing margin calculations in 1985-1996). In Finnish, an English abstract. Agricultural Economics Research Institute, Helsinki, Finland. Research Reports 214. 66 p.

Leahy, J.V. 1993. Investment in competitive equilibrium: The optimality of myopic behaviour. Quaterly Journal of Economics. November 1993, Issue 4, p. 1103-1133.

Lehtonen, H. 1996. A dynamic model for economic and policy analysis of Finnish agriculture. Master's Thesis. Helsinki University of Technology, Department of technical physics and mathematics. 122 p.

Lehtonen, H. 1998. A dynamic regional sector model of Finnish agriculture (DREMFIA) (in Finnish, an English abstract). Agricultural Economics Research Institute. Research reports 224. Helsinki.

Lehtonen, H., Linjakumpu, H., Knuuttila, M. & Marttila, J. 1999. Structural development of Finnish agriculture until 2008 (in Finnish, an English abstract). Agricultural Economics Research Institute. Research reports 232. Helsinki. 137 p.

Lihatalous 2/2000. Publication of Lihatalouden Keskusliitto (Union of meat processing industry).

Lihatalous 2/2001. Publication of Lihatalouden Keskusliitto (Union of meat processing industry).

Love, H.A. 1999. Conflicts between Theory and Practice in Production Economics. American Journal of Agricultural Economics, Vol 81, No. 3 (August 1999) 696-702.

Luomuliitto 2000. http://www.finfood.fi/finfood/luomu.nsf/pages/index.htm.

Maaseudun Tulevaisuus 2000. Maakiintiö ylittymässä 38 miljoonaa litraa. Maaseudun Tulevaisuus October 19, 2000, p. 4. A newspaper published by the Finnish Farmers' Union.

Maaseudun Tulevaisuus February 19 2000. A newspaper published by the Finnish Farmers' Union.

Maatalouspoliittinen työryhmä 1996. Maatalouspoliittisen työryhmän väliraportti. (The report of a working group of agricultural policy, published by the Ministry of Agriculture and Forestry). Maa- ja metsätalousministeriö. Helsinki.

McCarl, B.A. 1982. Cropping activities in agricultural sector models: A methodological proposal. American Journal of Agricultural Economics 64: 768-771.

Metcalfe, S. 1995. The economic foundations of technology policy. In: Stoneman, P. (ed.). Handbook of economics of innovation and technological change, p. 409-512.

Miller, T.A. 1972. Evaluation of Alternative Flexibility Restraint Procedures For Recursive Programming Models Used for Prediction. American Journal of Agricultural Economics, Vol 54, p. 68-76.

MKL 1995. Mallilaskelmat (Farm level production cost calculations). Suunnitteluosaston sarja A 24. Maaseutukeskusten liitto (Union of Rural Advisory Centres). Helsinki. 112 p.

MKL 1996a. Maatalouskalenteri 1996. Maaseutukeskusten liitto (Union of Rural Advisory Centres). Helsinki. 220 p.

MKL 1996b. Results of the Milk Recording in Finland 1995. Publications of Maatalouskeskusten liitto (Federation of Rural Advisory Centres in Finland) No. 904. ISBN 951-808-046-1. Helsinki. 42 p.

MKL 1997. Results of the Milk Recording in Finland 1996. Publications of Maatalouskeskusten liitto (Federation of Rural Advisory Centres in Finland) No. 915. ISBN 951-808-055-0. Helsinki. 42 p.

MKL 2000. Information pages of the Rural Advisory Centres in Finland. http://www.maaseutukeskus.fi/tuotantotuloksia.

MTTL 1999. Finnish Agriculture and Rural Industries 1998. Agricultural Economics Research Institute, Finland. Publications 91a. 94 p.

MTTL 2000. Finnish Agriculture and Rural Industries 1999/2000. Agricultural Economics Research Institute, Finland. Publications 95a. 95 p.

MTTL 2001. MTTL:ssa laadittu maa- ja puutarhatalouden vuoden 2000 kokonaislaskelmaa koskeva ennuste. (A forecast of the total calculations of agriculture for year 2001). Internal information of the Agricultural Economics Research Institute of Finland.

Mueller, G.P. & Day, R.H. 1978. Cautious Rolling Plans with Forecasting and Market Feedback. Chapter 10 in: Day, R.H. & Cigno, A. Modelling Economic Change. The Recursive Programming Approach.

Nelson, R.R. & Winter, S.G. 1982. An evolutionary theory of economic change. Belknap Press of Harvard University Press. Cambridge, Massachusetts and London. 437 p.

Niemi, J., Linjakumpu, H. & Lankoski, J. 1995. Regional structural development of Finnish agriculture until 2005 (in Finnish). Agricultural Economics Research Institute, Finland. Research Reports 204. 184 p.

Nijkamp, P. & Reggiani, A. 1998. The Economics of Complex Spatial Systems. North-Holland. 270 p.

Paris, Q. & Howitt, R.E. 1998. An Analysis of Ill-Posed Production Problems Using Maximum Entropy, American Journal of Agricultural Economics 80(1), p. 124-138.

Peltomäki, A. 2000. Tiukka alkuperävaatimus uhkaa luomulihan tuotantoa. Maaseudun Tulevaisuus August 12 2000.

Peltomäki, M. 2000. Elintarikkeiden hintamarginaalit vuosina 1997-1999 (the marketing margin calculations in 1996-1997). In Finnish, an English abstract. Agricultural Economics Research Institute, Helsinki, Finland. Working papers 2/2000. 35 p.

Pietola, K.S. 1997. A generalised model of investment with an application to Finnish hog farms. Agricultural Economics Research Institute, Finland. Publications 84. 113 p.

Pindyck, R.S. & Rubinfeld, D.L. 1995. Microeconomics. 3rd edition. Prentice Hall. 699 p.

PTT 1998. PTT Katsaus 1/1998. Pellervo Economic Research Institute. 69 p.

PTT 2000. PTT Katsaus 1/2000. Pellervo Economic Research Institute. 70 p.

Pyykkönen, P. 1996b. Maatalouden pääomakanta ja investointitarve eri rakennekehitysvaihtoehdoissa. (Capital of agriculture and the needs for investments in different scenarios of structural change). PTT:n raportteja ja artikkeleita 146. Espoo. 45 s.

Rantala, J. 1997. Maidon tuotantokustannukset taloustarkkailutiloilla (Costs of dairy production). Reports and discussion papers n:o 151. Pellervo Economic Research Institute. 78 p.

Riepponen, L. 1998. Maidon, viljan ja sianlihan tuotantokustannukset kirjanpitotiloilla (Production costs of milk, cereals and pigmeat on bookkeeping farms). In Finnish, an English abstract. Agricultural Economics Research Institute, Finland. Research Reports 222. Helsinki. 94-120 p.

Sairanen, A., Nousiainen, J. & Khalili, H. 1999. Korkean väkirehumäärän vaikutus maitotuotokseen ja tuotannon kannattavuuteen. Poster paper (P7) presented Agro-Food ’99 in February 2-4 1999, Tampere.

Salvatici, L. et al. 2000. Recent developments in modelling the CAP: hype or hope? Paper presented in 65th EAAE Seminar “Agricultural Sector Modelling and Policy Information Systems”, Bonn, Germany March 29-31, 2000. 21 p.

Samuelson, P.A. & Nordhaus, W.D. 1984. Economics. McGraw-Hill.

Sheldon, I.M. 1992. Imperfect Competition and International Trade: The use of Simulation Techniques. In: Sheldon, I.M. & Henderson, D.R. (eds.). Industrial Organization and International Trade: Methodological Foundations for Food and Agricultural Market Research. North Central Regional Research Project NC-194. Publication number 334. NC-194 Research Monograph Number 1. July 1992.

Shoven, J.B. & Whalley, J. 1992. Applying general equilibrium. Cambridge University Press. 299 p.

Silberberg, E. 1990. The structure of economics. A mathematical analysis. McGraw-Hill. 686 p.

Silverberg, G., Dosi, G. & Orsenigo, L. 1988. Innovation, diversity and diffusion. A self-organization model. Economic Journal, December 1988, vol. 98. p. 1032-54.

Simon, H. 1959. Theories of Decision Making in Economics. American Economic Review 49: 253-283.

Simon, H. 1986. Rationality in Psychology and in Economics, Journal of Business 59, No.2, Part. 2, S209-S224.

Soete, L. & Turner, R. 1984. Technology diffusion and the rate of technical change. The Economic Journal. p. 612-623. September 1984.

Statistics Finland 1995. Maatilatalouden yritys- ja tulotilasto 1994 (Business and Income Statistics of Farming. Finnish Official Statistics. Agriculture and Forestry 1995:8. 64 p. Helsinki.

Sterman, J.D. 1996. Comments by John D. Sterman. Journal of Economic Behaviour and Organisation Vol. 29 (1996), p. 251-252.

Stoneman, P. 1995. Handbook of economics of innovation and technological change. Blackwell handbooks in economics. Blackwell Publishers Ltd. 583 p.

Sumelius, J. 1993. A response analysis of wheat and barley in nitrogen in Finland. Journal of Agricultural Science in Finland 2(6): 465-479.

TIKE 1996. Farm Register 1995. Information Centre of the Ministry of Agriculture and Forestry. Official Statistics of Finland. Agriculture and Forestry 1996: 4. 171 p.

TIKE 1999a. Yearbook of Farm Statistics 1999. Information Centre of the Ministry of Agriculture and Forestry. Official Statistics of Finland. Agriculture, Forestry and fishery 1999: 12. 262 p.

TIKE 1999b. Farm Register 1998. Information Centre of the Ministry of Agriculture and Forestry. Official Statistics of Finland. Agriculture and Forestry 1999: Y. 260 p.

TIKE 2000. Farm Register 1998. Information Centre of the Ministry of Agriculture and Forestry. Helsinki. 171 p.

van Tongeren, F. 2000. Review of agricultural trade models: An assessment of models with EU policy relevance. Paper presented in 65th EAAE Seminar “Agricultural Sector Modelling and Policy Information Systems”, Bonn, Germany March 29-31, 2000. 12 p.

Tyers, R. & Anderson, K. 1992. Disarray in world food markets. A quantitative assessment. Cambridge University Press. Cambridge. 444 p.

Törmä, H. (ed.). 1989. General Equilibrium Tax Model of the Finnish Economy. University of Jyväskylä, Department of Economics and Management, Publications 79 (in Finnish).

Törmä, H. & Rutherford, T. 1992, A General Equilibrium Assessment of Finlands’s Grand Tax Reform, University of Jyväskylä, Reports from the Department of Economics and Management 15.

Törmä, H. & Rutherford, T. 1993. Integrating Finnish agriculture into EC. Government Institute for Economic Research. Helsinki. 83 p.

Ylätalo, M. (ed.). 1996. Maatalousyritysten sopeutuminen EU:ssa vallitseviin hintasuhteisiin (The EU and Economic Adjustment of Finnish Agriculture. A Production and cost-Theoretical Approach to Plant and Animal Production). in Finnish, an English abstract. University of Helsinki, Department of economics and Management. Publications No. 12, Agricultural Economics. 258 p.

Varian, H. 1992. Microeconomic Analysis. 3rd edition. Norton. 506 p.

de Vriend, N.J. 1996. Rational behaviour and economic theory. Journal of Economic Behaviour and Organisation 29: 263-285.

Witt, U. 1993. Emergence and Dissemination of Innovations: Some Principles of Evolutionary Economics. In: Day, R.H. & Ping, C. (eds.). Nonlinear Dynamics and Evolutionary Economics. Oxford University Press. 335 p.

Appendix

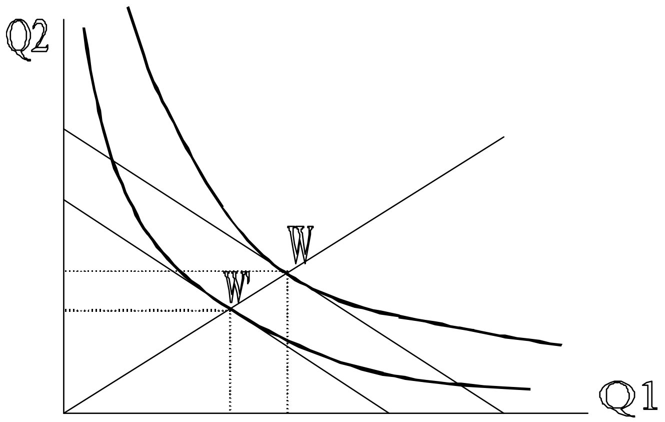

Figure A-1. Homotheticity of the utility function.

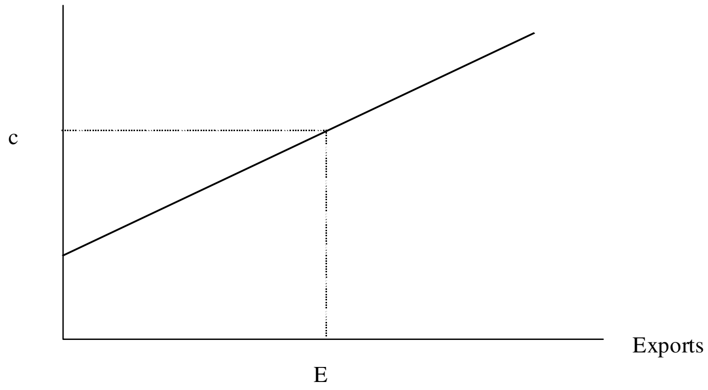

Figure A-2. Export cost function.

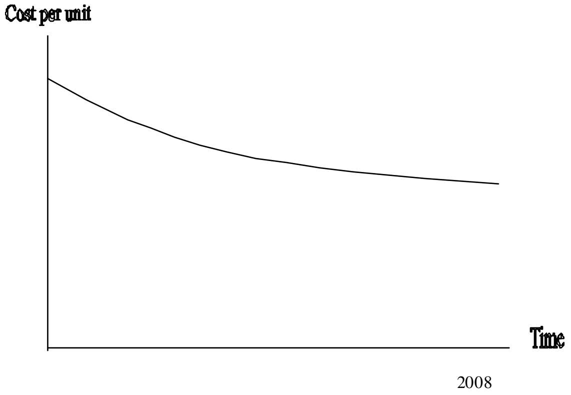

Figure A-3. Decrease in use of inputs per hectare and animal.

Maatalouden taloudellisen tutkimuslaitoksen julkaisuja
Publications of the Agricultural Economics Research Institute

No 83 Miettinen, A., Koikkalainen, K., Vehkasalo, V. & Sumelius, J. 1997. Luomu-Suomi? Maatalouden tuotantovaihtoehtojen ympäristötaloudelliset vaikutukset -projektin loppuraportti. 124 s.

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No 89 Puurunen, M. 1998. Suomen maa- ja puutarhatalouden sopeutuminen EU-jäsenyyden alkuvuosina. MATEUS-tutkimusohjelman yhteenvetoraportti. 165 s.

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Koikkalainen, K., Haataja, K. & Aakkula, J. Maatalouden ympäristötuen perustuen merkitys maatilojen taloudelle. s. 78-132.
Peltola, J. Maatalouden ympäristöohjelma 1995-1999:n vaikutus keinolannoitteiden käyttöön - ekonometrinen analyysi. s. 133-159.

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No 95a MTTL 2000. Finnish Agriculture and Rural Industries 1999/2000. 95 p.

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No 97a MTTL 2001. Finnish Agriculture and Rural Industries 2001. 95 p.