A regional econometric sector model for Danish agriculture
a documentation of the regionalized ESMERALDA model

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A Regional Econometric Sector Model for Danish Agriculture

A Documentation of the Regionalized ESMERALDA model

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Knud Kristensen

København 2001

Contents

Preface

This report describes and documents the latest version an econometric sector model of the Danish agricultural sector. Particular attention is given to the description of the methodology applied, the data used and the description of estimated behavioural parameters of the Danish agricultural sector. A forthcoming report from the institute will supplement the present report by giving a more verbal introduction to the model, including analyses of a few illustrative scenarios.

The development and the use of the model is an integral part of the research project entitled "Agriculture in rural districts: economy and development" financed by the Directorate for Food, Fisheries and Agribusiness under the Danish Ministry of Food, Agriculture and Fisheries. The overall objective of the research project is to provide a basis for evaluating the development of rural areas and the possibilities for influencing this development through choice of political actions and promotions of alternative activities complementary to existing activities. The emphasis is on a holistic model based approach where the agricultural sector's economic importance is seen as an integral part of the local communities and their economy, and environmental factors and matters relating to the natural landscape are taken into account. The project is conducted in collaboration with the Institute of Local Government Studies.

The report has been prepared by Senior researcher Jørgen Dejgård Jensen and research assistants Martin Andersen and Knud Kristensen. Furthermore, the model development has drawn on data work and statistical analyses by Stine Hjarnø Jørgensen and Malene Kragh Petersen. Research Director Søren E. Frandsen has participated in the editing process.

Danish Institute of Agricultural and Fisheries Economics, December 2001

Ole P. Kristensen

Executive summary

Through the last decade, agricultural policy has changed significantly in the European Union. This is partly a result of the pressure for removing support measures, which distort international trade (e.g. price support in terms of export subsidies, import duties and market intervention), but also a result of an increased awareness of the needs for differentiating the regulations and interventions between farms and between regions. As an example, there is an increased focus on the economic role of agriculture in rural areas lacking behind in attracting other industries. There is also an increasing focus on the environmental and landscape impacts of agricultural activities and the variation in such impacts from different farm types. Thus, the range of agricultural policy instruments moves in the direction from horizontal measures to more targeted and differentiated instruments. This development is expected to continue in the future.

In order to perform quantitative assessments of such more differentiated instruments in agricultural policy, there is a need for quantitative economic models, which take into account the regional diversities within the agricultural sector, and the possibility for representing such policy instruments properly. Together with another report (Jensen, 2002), this report describes and documents an econometric sector model – ESMERALDA – which

- enables economic analyses of changes in the Danish agricultural sector at the national as well as the local (municipality) level,
- integrates agricultural sector analysis with other model tools, e.g. macro-economic models at the national and local level, and thus enables more holistic analysis of the economic development in Danish rural districts and in the country as a whole, and
- improves the possibilities for integrated economic and environmental analysis related to agriculture, e.g. environmental problems with a non-point source nature and policy instruments addressing the farm level.

The present report provides a formal documentation of the theoretical principles and econometric methodologies applied for constructing the model, whereas Jensen (2002) gives a more verbal introduction to the model, including a number of illustrative examples of model applications.

ESMERALDA describes the agricultural production, demand for inputs, land allocation, livestock density and various economic and environmentally relevant variables on representative Danish farms, and subsequently in the Danish agricultural sector at relevant levels of aggregation. The model covers 14 lines of agricultural production, of which 11 yield a marketed output: (7 cash crops, 2 cattle sectors, pigs and poultry), whereas the output from the remaining 3 roughage crop sectors is mainly consumed on-farm. Furthermore, the model describes the demand for 7 variable inputs (energy, labour, fertilisers, pesticides, contract operations, purchased roughage and concentrate feeds).

A basic assumption underlying the model's description of these variables is that farmers exhibit economic optimisation behaviour. The model simulates economic behaviour on a large sample of representative Danish farms as a three-stage procedure, comprising the determination of:

- cost minimising composition of variable inputs for given input prices,
- profit maximising yield levels in respective lines of agricultural production for given input and commodity prices and
- profit maximising land allocation and livestock densities for given prices and quantitative restrictions.

The representative farms are subsequently aggregated into national, regional/local or typology aggregates using a set of aggregation factors, which aim at ensuring the maximum feasible consistency with existing structural population variables at the relevant levels of aggregation. Thus, key parameters in the model are: a) parameters describing the three stages of economic behaviour at the farm level, and b) the set of aggregation factors for aggregating farm data to higher levels. Empirical estimation of these key parameters is the main issue in the present report.

Econometric estimation of the key behavioural parameters has been carried out using panel data econometric methods on a large set of farm accounts data. In order to allow for major technological differences between farm types and soil types, distinction has been made between four farm types: part-time farms and full-time crop, cattle and pig farms, and between farms on two different soil types: loam and sand – in total eight different groups of farms.

Selected estimated behavioural parameters for the eight farm groups are given in the table below. The parameters include three types of parameters: yield-endogenous own-price elasticities, output-compensated own-price elasticities and elasticities of transformation between different production activities. The parameters are described in more detail in chapters 4-6, and in appendix D and F.

Selected estimated behavioural parameters for all eight farm types

	Crop, loam	Crop, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Part-time, loam	Parttime, sand
Yield-endogenous ("Marshallian") own-price elasticities								
Fertiliser	-0.636	-0.578	-0.634	-0.468	-0.079	-0.151	-0.750	-0.474
Pesticide	-0.932	-0.765	-0.740	-0.729	-0.704	-0.983	-0.967	-0.985
Labour	-0.130	-0.279	-0.242	-0.193	-0.115	-0.078	-0.358	-0.272
Output-compensated ("Hicksian") own-price elasticities								
Fertiliser	-0.583	-0.541	-0.631	-0.464	-0.074	-0.148	-0.717	-0.449
Pesticide	-0.902	-0.755	-0.735	-0.722	-0.699	-0.980	-0.952	-0.968
Labour	0.019	-0.156	-0.210	-0.153	-0.079	-0.050	-0.216	-0.152
Elasticities of transformation between production activities								
Land-non-land	-	0.254	-	-	0.312	0.298	-	-
Cereals-pulses/rape	2.549	0.849	-	3.811	1.219	0.201	-	0.886
Spring barley-wheat	0.381	-	0.416	0.963	1.350	2.397	-	-

Yield-endogenous (or Marshallian) price elasticities reflect the combined effects of yield adjustments (change in crop yield per hectare or yield per animal) and input substitution for given land allocation and livestock activity. Yield adjustments are due to changes in the input-output price relationships, whereas the input substitution effects are due to changes in price relations between different inputs. There seem to be similarities in the own-price elasticities for many of the inputs across most farm types, but also some systematic patterns concerning farm and soil types. For example, the price elasticities for purchased fertilisers are around –0.6 for most farm types on loamy soil and –0.5 for most farm types on sandy soil. Pig farms, however, seem to have significantly lower price elasticities for fertilisers (around –0.1). This may reflect a high self-sufficiency with animal manure on these farms, but it may also reflect that pig farmers are less concerned about partial optimisation of fertilisation than e.g. crop producers, because the cost of fertiliser is a minor share of pig farmers' total costs. A pattern similar to that for fertilisers is observed with respect to labour, whereas no systematic pattern across farm and soil types seems to be present in the case of pesticides. It should be noted that cross price elasticities are less homogenous, because they to a higher extent also reflect differences in input composition on the eight farm types.

As indicated above, the yield-endogenous price effect may be decomposed into a yield effect and an input substitution effect. Output-compensated (or Hicksian) own-price elasticities represent the latter component, i.e. the pure short-run input substitution effect triggered by a change in the considered price, e.g. the price of fertilisers, assuming that yield levels (per hectare or head) as well as activity levels remain constant. These elasticities are in general lower (in absolute value) than the yield-endogenous elasticities, reflecting the fact that the yield effect of an input price increase in general is non-positive. Across farm and soil types, the output-compensated price elasticities show patterns similar to those of the yield-endogenous elasticities above. Thus, for fertilisers and labour, the elasticities appear to be larger (in absolute value) on loamy soil than on sandy soil, whereas the pattern is less obvious for pesticides.

The difference between the Marshallian and Hicksian elasticities represent the yield effect of an input price change. For example, the own-price effect of a fertiliser price change due to the pure crop yield effect can be calculated as -0.053 for crop farms on loamy soil. Thus, the yield effect constitutes a relatively small share of the total effect of input price changes on input use.

Elasticities of transformation represent changes in the composition of agricultural activities due to changes in the economic returns in the respective activities. Specifically, the elasticities describe the percentage change in the ratio of activity levels due to a percentage change in the ratio between economic returns of the two activities. For example, if the economic returns to non-land based (pig and poultry) production increases by one per cent while keeping the economic return to land-based activity (crop and cattle production) unchanged, the number of pigs/poultry per hectare increases by 0.254 per cent on crop farms on sandy soil. Or if the economic returns to spring barley area increases by one per cent relative to that of wheat, the ratio between areas for spring barley and wheat will increase by 0.381 per cent for crop farms on loamy soil. Due to data shortages, it has not been possible to estimate all these elasticities. However, the results in the table seem to indicate that the difference between farm and soil types is relatively limited concerning the transformation between landbased and non-landbased activities. On the other hand, farms on loamy soils seem to be more eager to switch between cereals and pulses/rape than farms on sandy soils, whereas the opposite is the case for the switch between spring barley and wheat, as the elasticities are higher for sandy soil farm types.

The above results demonstrate some similarities, but also systematic differences between the different farm groups. Thus, compared with a more uniform approach to agricultural sector modelling, the current framework must be expected to yield a more precise description of economic behaviour in the agricultural sector, because the variation in behavioural parameters are explicitly taken into account.

The combination of the farm-based approach and an aggregation scheme ensuring consistency with aggregate figures has proven useful for several types of economic analysis related to the agricultural sector. Some illustrative applications of the model are described in Jensen (2002), where economic impacts of various changes in the economic conditions are assessed for the agricultural sector as a whole and for different groupings of the agricultural sector. The model has also proven useful for spatial analyses (Rygnestad et al., 2000), where the model has been combined with GIS-data in order to investigate the economic potentials for aforestation and drinking water protection within a specific study area in Denmark.

The combination of a large number of diverse farm types and a consistent aggregation scheme also enables linkage with other analytical tools. One example at the aggregate level is a set of scenario analyses, where the model is linked to macro-economic models at the national as well as the municipality level in order to assess the impacts of changes in agricultural and agri-environmental policies on the economy of Danish rural municipalities (Hasler et al., 2002). Another example is the use of the model in environmental assessment of macroeconomic projections (Andersen et al., 2001).

The farm-level basis has also proven useful for analysing environmental policy instruments, because it takes into account the diversity of farms, thus enabling analysis of instruments, which address the farm level. For example, Jensen et al. (2001) supplement the model with detailed data for nitrogen balances and pesticide use, and the expanded framework has been used for economic comparison of transferable versus non-transferable reduction requirements on the use of pesticides. The high level of disaggregation is expected to make the link with specific environmental satellite models (e.g. a model for nitrate leaching) relatively easy.

As mentioned at the outset, the main part of this report provides a technical documentation of the specification and estimation of ESMERALDA. Chapter 1 provides an introduction to the problems addressed by ESMERALDA, as well as a discussion of the similarities and differences with a previous version of the model, whereas chapter 2 gives a structural overview of the model. In chapter 3, the data underlying the model are presented, and chapters 4-6 describe the theoretical specification and econometric estimation of model's three types of behavioural equations at the farm level: input composition equations (chap. 4), yield equations (chap. 5), and activity level equations (chap. 6). Chapter 7 describes and demonstrates the aggregation procedure used for aggregating variables from the farm level to the national or local level. Finally, chapter 8 draws some perspectives from the work and discusses some of the strengths and limitations to the approach. Readers with main interest in model potential applications may thus skip the relatively technical chapters 3-7, and perhaps supplement with illustrative applications from Jensen (2002).

1. Introduction

The present chapter provides an introduction to the contents of the report, including a discussion of the aims of the model, a brief overview of existing approaches to agricultural sector modelling, and a short discussion of the main similarities and differences between the current and a previous version of the model.

1.1. Background and objectives of the model

The roles of the agricultural sector in rural development has gained attention during the last decade, in the European Union and other regions among the industrialised countries. This increased attention can be seen in the light of an ongoing structural development in most industrialised countries. On the one hand, the structural development implies growth in manufacturing and service industries, whereas primary industries are stagnating. Consequently, the significance of agriculture and other primary sectors for income and employment is on the decrease. On the other hand, agricultural activities are concentrated on still fewer production units, in terms of a rapid development in farm structure and a relatively strong growth in labour productivity in the farming sector, with consequences for agricultural employment, rural landscapes etc. At the same time, parttime farms constitute an increasing share of the total number of farms.

The focus on rural development can however also be seen in the light of efforts to liberalise international trade in agricultural products, as well as ongoing or expected changes in environmental policies related to agriculture. A major concern in this respect is, to which extent the economy in (agriculture-based) rural areas will be affected by such changes in the economic conditions surrounding the agricultural sector.

The increasing focus on rural development and environmental aspects, as well as the pressure to remove trade-distorting policy instruments, has implied a movement in the range of agricultural policy instruments in the direction from horizontal measures to more targeted and differentiated instruments. This development is expected to continue in the future.

In order to perform quantitative assessments of such questions, concerns and policy trends, there is a need for quantitative economic models, which take into account the regional diversities in the agricultural sector and in the economic structures in general, as well as the interactions between the agricultural and other economic sectors.

Based on these considerations, the objective of the present model is threefold:

1. to enable economic analyses of changes in the Danish agricultural sector at the national as well as the local (municipality) level. The scope for economic analysis includes comparative analysis of different situations as well as different scenarios for development of the agricultural sector.
2. to integrate the agricultural sector analysis with other model tools, e.g. macro-economic models at the national and local level, and hence enable more holistic analytis of the economic development in Danish rural districts, and Denmark as a whole.
3. to improve the possibilities for integrated economic and environmental analysis related to agriculture – specifically environmental problems with a non-point source nature.

Agricultural sector economic analysis at the national and local level

The model aims at representing the Danish agricultural sector at the national level as well as for each of the 275 municipalities in Denmark, where results from the individual municipalities add up to the national aggregate. The modelling approach is based on farm data from a large sample of Danish farms, and the representation of individual municipalities is based on an aggregation scheme, taking into account characteristics of the farm structure in the respective municipalities.

Integration of agricultural sector analysis with other model tools

The development of the model has aimed at facilitating the link to macro-economic models, in order to enable consistent economic analyses, which take into account the interrelations between agriculture and other economic sectors – including the feedback of price responses and the consistency of relevant behavioural parameters.

Integrated economic-environmental analyses

Due to the farm-based structure of the ESMERALDA-model[1], it is relatively well-suited for analyses of fairly detailed environmental policy regulations, and the municipality focus of the model also enables analysis at a fairly geographically disaggregated level, a feature which is useful for analyses addressing site-specific environmental issues.

1.2. Status of agricultural sector modelling

ESMERALDA can be characterised as an agricultural sector model, although this term has been used for various analytical concepts and methodologies during the last 2-3 decades. Depending on the issue to be analysed various approaches have been applied, spanning the range from the highly detailed specific farm level (see e.g. Jacobsen et al., 1999) over the agricultural sector level to the global general economic level (for a review of international trade models, see e.g. van Tongeren et al., 2000). In the following, we use the term 'agricultural sector model' for a model focusing on the agricultural sector at the national or regional level.

Internationally, the dominating approach to agricultural sector modelling has been that of mathematical programming[2], whereas the use of econometric methods for establishing large agricultural sectoral models has been less extensive in the most recent years[3].

The mathematical programming approach builds on explicit optimisation of an objective function (e.g. minimisation of costs, maximisation of agricultural profits or some equilibrium/welfare measure), subject to a number of restrictions (e.g. resource constraints, crop rotation restrictions etc.). The explicit formulation of technical restrictions etc. provides an opportunity for model specification at a relatively detailed level, including for instance the switch between different manure handling technologies, different feeding strategies etc., but also requires proper specification of all details. The use of mathematical programming for agricultural sector analysis has been exten-

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[1] Econometric Sector Model for Evalutating Resource Application and Land use in Danish Agriculture.

[2] Examples are Stryg et al., (1995), Wiborg (1999), Day (1963), Eurostat (1995), Heckelei & Britz, (2000), Lehtonen (1999), Bauer & Kasnakoglu (1989), Osterburg et al. (2000), Flury et al. (2000), Malitius et al. (2000), Helming et al. (2000), Jacobsen et al. (1999).

[3] See however Oude Lansink & Peerlings, 2000, for a survey.

sive since the work of Day (1963). One fundamental problem in mathematical programming models has been the calibration problem, i.e. the ability of the model to reproduce empirical observations. Data availability often prescribes a linear specification, but such linear programming models tend to produce “corner solutions”, which typically deviate from empirically observed situations. The use of mathematical programming methods has however undergone a renaissance since the launch of socalled ‘Positive Mathematical Programming’ (Howitt, 1995), which has further been developed by the use of Maximum Entropy methods in the calibration procedures, despite the lack of empirical quantitative foundation for the smooth response patterns implied by the quadratic calibration.

Normally, an econometric model is not formulated as an explicit optimisation problem, although the econometrically estimated behavioural relations implicitly reflect economic optimisation. Compared with the mathematical programming approach, the econometric approach is less sensitive to having full knowledge of all technical details in the production processes (although more knowledge is better than less knowledge – also in econometric models). Econometric models are empirically founded on historical variations in data. Hence, the validity of the behavioural parameters in an econometric model is in principle limited to the data ranges, for which these parameters are estimated.

1.3. New developments compared to an earlier version of ESMERALDA

The model described in this paper can be seen as a further development of an earlier version of ESMERALDA, although the new version differs significantly from the previous version in several respects. The following gives a brief overview of the main similarities and differences between the two model versions. For more details on the old model version, see Jensen (1996).

The current model version describes production in 14 (which can be disaggregated into 21) of the most important agricultural sub-sectors: wheat, winter barley, other cereals (spring barley, rye, oats, other), pulses, rape, potatoes, sugarbeets, fodder beets, green fodder in rotation (grass and silage cereals), permanent grass, dairy cattle (dairy cows and heifers), beef cattle (slaughtering calves and nurse cows), pigs (sows and baconers) and poultry in a relatively simple dynamic setting. The earlier model version was purely static comparative and described production behaviour in 19 sub-sectors. Among the variables modelled in both model versions are activity levels (hectares or livestock units) in the sub-sectors, intensity variables (output and input use per activity unit) in the sub-sectors, and thus total production and input use.

In contrast to the new version, where focus lies on optimisation at the farm level, the old model version covers the aggregate (national) level in each agricultural sub-sector, and the model structure assumes separability between different agricultural sub-sectors, in that optimization in the individual sub-sectors determines production intensity, and optimization at the aggregate level (for given production intensity) determines the activity levels. In both versions, most product and input prices are assumed to be exogenous, due to the fact that the Danish agricultural sector accounts for only a small part of the entire EU agricultural production as well as the total Danish economy, and thus the market power on both output and input markets is limited. Some of the prices of internally produced inputs (roughage and some other non-traded feeds and breeding animals) are endogenous, however.

Both model versions are based on an econometric approach, where model equations are formulated on the basis of an assumption of economic optimisation behaviour using duality theory and the translog functional form. In the old version, econometric estimations were based on aggregate farm accounts data at the sub-sector level, provided by the Danish Institute of Agricultural and Fisheries Economics. In order to enable the econometric estimation, a number of separability assumptions were imposed, because such assumptions reduce the number of parameters to be estimated econometrically, and this was necessary, given the number of observations available for the estimation. The new version is estimated on farm level panel data from a large sample of Danish farms, which reduces the requirement for separability assumptions.

The old model version links the individual sub-sectors through a set of model conditions, i.e. identities and physical restrictions (e.g. land availability), economic equilibrium conditions, regulations, etc. Hence, the effects of specific regulations on e.g. land use can be assessed in the model, provided that the model implementation of the regulation makes sense at an aggregate level. In the new model version, specific equations for land allocation, livestock density etc. have been estimated directly.

Thus, the new model version presented in this report shares some characteristics with the old version, in that it is based on an econometric approach, duality theory, translog functions, economic account data from Danish Institute og Agricultural and Fisheries Economics and an explicit modelling of the linkages between different lines of agricultural activity. However, there are also significant differences between the two model versions.

2. Overview of the model

This chapter intends to provide an overview of the model, and the interrelations between the different components of the model. Although there are parallels, it may be useful to distinguish between the structure of the model itself, and the structure of the econometric estimation procedure.

2.1. General features of the model

The purpose of the model is to describe production, input demands, land allocation, livestock density and various economic and environmentally relevant variables on representative Danish farms, and subsequently in the Danish agricultural sector at relevant levels of aggregation. These variables are assumed to be functions of the economic conditions facing the farms, including agricultural prices, economic support schemes, quantitative regulations etc. A basic assumption underlying the model's behavioural description is that farmers exhibit economic optimisation behaviour.

The model covers 14 lines of agricultural production (plus fallow), of which 11 yield a marketed output:

- 7 cash crops: spring barley (covering spring barley, rye and oats), winter barley, wheat, pulses, rape, potatoes and sugar beets
- 3 roughage crops: fodder beets, green fodder in rotation (covering grass in rotation and silage cereals) and permanent grass
- 2 cattle sectors: dairy cattle (covering dairy cows and rearing cattle) and beef cattle (covering nurse cows and slaughtering calves)
- pigs (covering sows and baconers)
- poulty
- fallow

Of these, the outputs from roughage and fallow are not marketed in the model. Fallow is not supposed to yield an output at all, and the production of roughage is assumed to serve as on-farm input in cattle production. Along with the 11 commercial outputs, the model determines demands for 7 variable inputs in the short run (energy, labour, commercial fertilisers, pesticides, contract operations, purchased roughage and purchased concentrate feeds). In the longer run, the model determines changes in activity levels (land allocation and livestock density), input of capital and derived effects on outputs and demands for short-run variable inputs. Based on changes in prices, quantities etc., a number of economic variables can be determined: output value, variable costs, gross margin etc.

The model is based on anonymous farm account data from 1000-2000 Danish farms per year in the period 1973/74 to 1995/96. These data comprise land use, livestock herds, labour and capital input, output revenues from different agricultural products and variable input costs at the farm level.

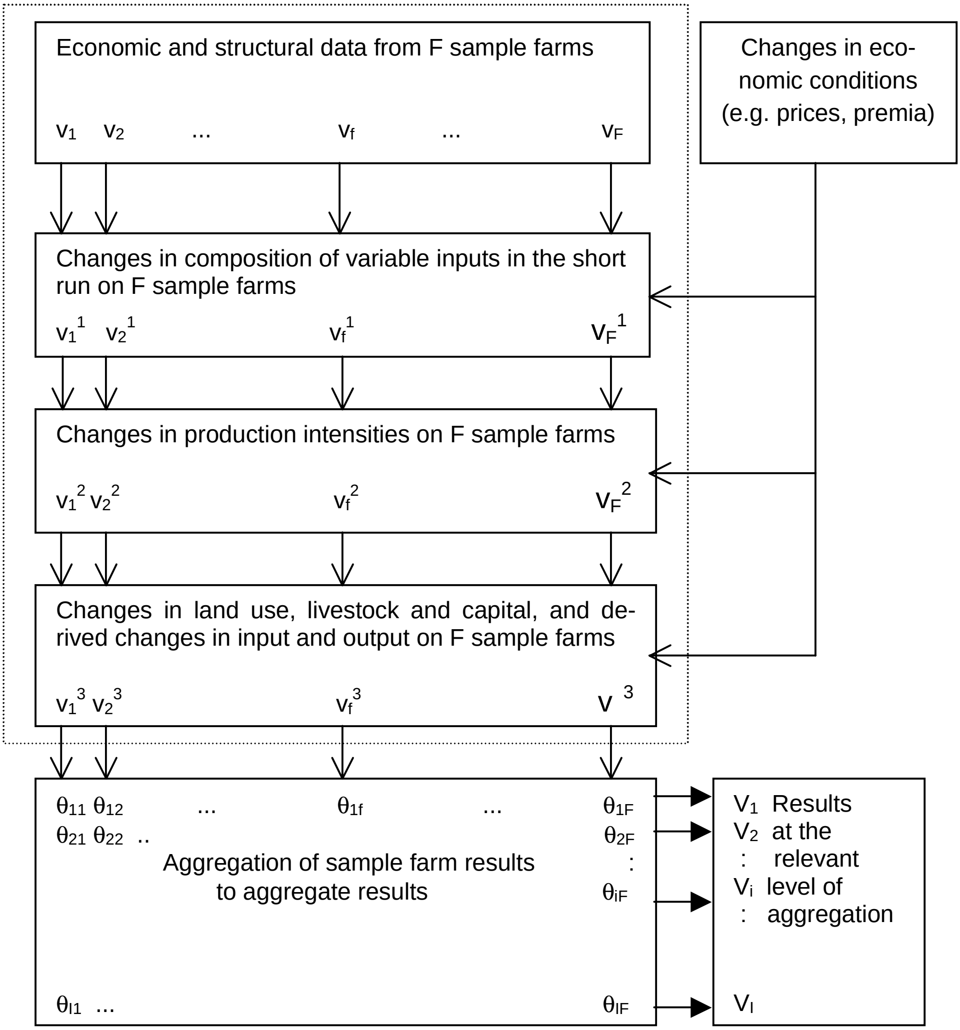
2.2. Structure of the model

The main principle in the ESMERALDA model is to determine economic behaviour on a number of representative Danish farms, and subsequently aggregate these farm level results to the relevant level or type of aggregation. The economic behaviour at the farm level includes determination of input composition, production intensity in individual lines of production as well as activity levels (numbers of hectares or animals) in each line of production. Examples of relevant aggregation schemes could be the construction of geographic (national or regional/local) or typologic (main production, farm size etc.) aggregates. The overall structure of the model is illustrated in figure 2.1.

Model analysis is based on data from one year's sample in the agricultural accounts data base (approximately 2000 farms). The contents of the dotted box in the figure represent behaviour at the farm level on each of these representative farms, as response to changes in economic conditions – represented by the upper right module in the diagram. Farm level adjustment takes place in three stages:

1) cost minimising adjustments in the composition of variable inputs,
2) short-run profit maximising adjustments in the yield levels in individual subsectors (keeping land allocation and livestock numbers constant), and derived adjustments in the use of variable inputs
3) adjustments in activity levels (land allocation, livestock numbers) and capital, and derived changes in output and use of variable inputs

Figure 2.1. Overview of ESMERALDA



In each stage, the behavioural adjustments (e.g. to price changes) are determined by econometrically estimated behavioural parameters (e.g. price elasticities etc.). Specifically, 8 sets of behavioural parameters have been estimated, representing 8 main farm types (part-time farms and full-time crop, cattle and pig farms on loamy and sandy soil, respectively). To each farm in the model, the most relevant of these 8 sets of parameters is attached.

The part below the dotted box in figure 2.1 represents the aggregation of individual model farms to the relevant level of aggregation. The aggregation is carried out by means of an aggregation matrix, which contains aggregation factors for each model farm to each of the relevant aggregates. Hence, the aggregation matrix represents the farm structure related to the considered grouping of farms. The aggregation matrix is assumed to be independent of the economic conditions specified in the upper right module. This assumption might be considered as a restrictive one. However, a study by Rasmussen & Wiborg (1996) indicates that developments in the Danish farm structure seems to have been fairly unaffected by observed changes in prices and regulations.

The developed model structure can be considered as a refinement of the approach applied in Schou et al. (1998, 2000). The model structure has similarities with the approach used by Osterburg et al. (2000), although their study is based on mathematical programming simulation at the farm level.

2.3. Outline of the econometric estimation procedure

The econometric estimation procedure applied for providing estimates of the behavioural parameters in the farm level adjustments generally follows the stages outlined in the simulation model. Hence, the estimation procedure consists of three stages – with a separate estimation model in each stage:

1) model of short run cost minimisation problem for given yield and activity levels. The model determines the cost minimising composition of energy, labour, purchased fertilisers, pesticides, external services and purchased feeds for given prices of these components as well as given yield and activity levels in the respective agricultural sub-sectors (described in detail in chapter 4).
2) extending short run cost minimisation model to a short run profit maximisation model, allowing yield levels to adjust, but maintaining activity levels in the respective sub-sectors (described in detail in chapter 5).
3) model of medium- and long run profit maximisation in terms of adjustments in land allocation, livestock numbers and capital input (described in detail in chapter 6).

All three stages of model formulation and estimation are based on the dual approach (see e.g. Chambers, 1988), where farmers' economic optimisation problems are specified in terms of cost or profit functions. In all three stages, the translog functional orm has been applied. Stages 1 and 2 have been formulated and estimated as static relationships, whereas the estimations in stage 3 build on a separable dynamic formulation of the long-run translog profit function.

2.4. Application and limitations of the model

In its present version, the model can be used for economic – static-comparative or dynamic – analysis of changed conditions in the Danish agricultural sector, e.g. price changes or restrictions on the production behaviour. The farm-based structure of the model and the aggregation scheme yields the opportunity to distinguish economic effects on different farm types, in different regions etc.

A general feature of econometric models is that they are based on behavioural equations estimated on historical data. This feature may be a strength because the estimated behavioural parameters reflect actually observed behaviour. It may however also be a potential limitation to the use of the model, because the model can only be validated within the data intervals spanned by the historical observations. Thus, applying an econometric model for analysing changes beyond historical variations is always problematic[4]. Another limitation to the econometric approach is that econometric estimation is restricted by the amount of available data. This may for example limit the potential for analysing detailed issues related to the use of fertilisers or pesticides, because the data material on these issues is rather limited[5].

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[4] It may however be noted, that such analyses are also problematic in other analytical frameworks.

[5] However, Jørgensen & Jensen (2000) have proposed a solution to the latter problem.

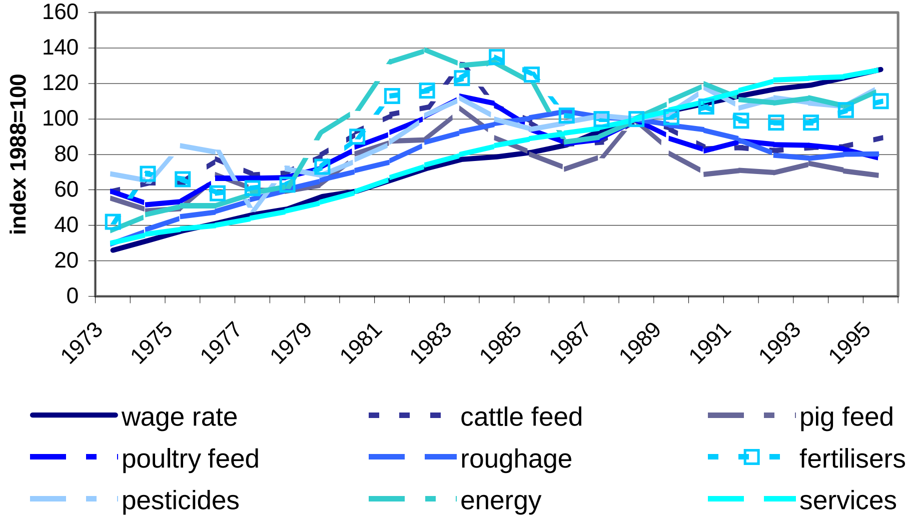
3. Data

This chapter describes the data material used for the econometric estimations and simulations. The data material is combined from different sources, where the main contributions stem from agricultural price statistics and agricultural accounts data at the farm level. These sources, as well as the preparation of data for the econometric estimation, are described in the following.

3.1. Agricultural price data

The price data for variable inputs used in agricultural production are shown in figure 3.1. The main source of data has been the annual price statistics provided by the Danish Institute of Agricultural and Fisheries Economics (1997c), supplemented with data from Statistics Denmark and the Organisation of Danish Poultry Producers.

Figure 3.1. Agricultural input prices, 1973-95



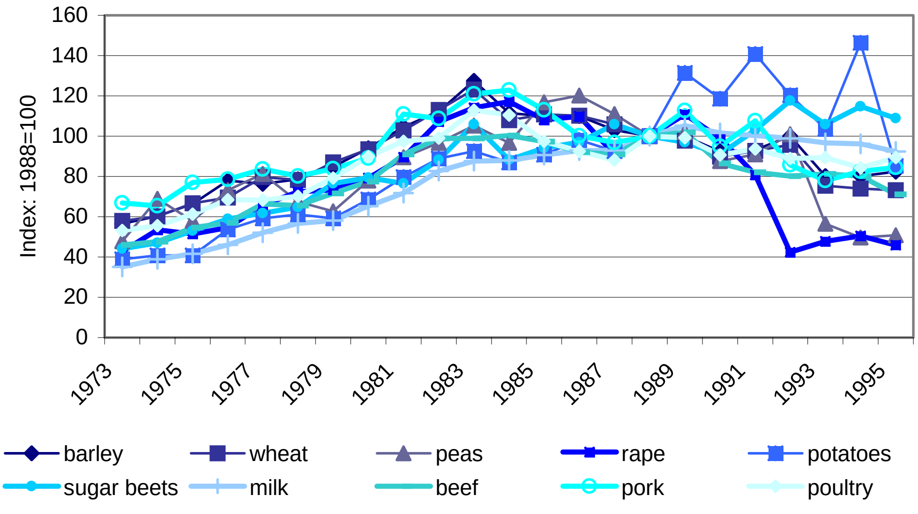
For some of these input prices, the underlying input is not necessarily homogenous over time. For example, the composition of fertiliser and pesticide use has varied significantly during the considered period, and the same problem could be perhaps be claimed in the case of the other inputs as well. Assuming that the price data in figure

3.1 can be considered as proper index representations of the respective input categories, and assuming separability between the input categories represented by the price series, the above price data are suitable for the estimation purpose, although interpretation of the results must take into account the potential limitations due to this problem.

A general impression from the figure is that prices increased more rapidly in the 1970'ies and early 1980'ies, due to a relatively high general inflation in that period, whereas they have become more stable since the mid-1980'ies. Feed prices are mutually correlated, and so are the prices of energy, fertilisers and pesticides. The wage rate seems to have been developing at a fairly stable rate.

Figure 3.2 illustrates the applied price data for agricultural outputs.

Figure 3.2. Prices of agricultural products, 1973-95



As was the case with agricultural inputs, the increases in agricultural output prices were steeper in the first half of the data period, due to general inflation in the Danish economy. Since the mid-1980'ies, the prices of agricultural products have exhibited a decreasing pattern. For beef and crops, this decrease has been strengthened by the

MacSharry reform of the Common Agricultural Policy in 1992-93, implying substantial reductions in price support (replaced by area and headage premia).

Main sources for these data are Danish Institute of Agricultural and Fisheries Economics (1997c), Statistics Denmark and the Organisation of Danish Poultry Producers. In contrast to the input price data, the outputs underlying the price data in figure 3.2 are more well-defined.

3.2. Farm level accounts data

The economic behaviour of Danish farmers is represented by a large set of anonymous individual economic accounts data provided by the Danish Institute of Agricultural and Fisheries Economics. The dataset is constructed from a stratified sample of annual farm accounts drawn from the total population of Danish farmers to obtain representativity in all relevant respects (cf. Danish Institute of Agricultural and Fisheries Economics, 1997a). The dataset consists of 24,690 observations and it covers the period from 1973 to 1995. The number of observations included in the dataset from year to year varies but in general it lies around 1,500 accounts per year. Around 20 per cent of the sample is replaced each year. Hence, farms are on average represented in the sample around 5 subsequent years. To enable micro-econometric analysis of the production behaviour in the Danish agricultural sector only farms represented at least two years are included in the dataset, which can be characterised as an unbalanced panel dataset.

The dataset is divided into eight subsets according to farm type in order to obtain a reasonable level of homogeneity. Hence, four farm types (part-time farms and full-time crop, cattle and pig farms) on two soil types (loam and sand) are distinguished. These eight farm categories are expected to reflect the main sources of variation among farms. For example, attitudes towards economic optimisation may differ between full-time and part-time farmers, because the latter often have other income sources. Fertilisation behaviour may differ between crop and livestock farms due to the self-supply with animal manure on the latter, and between cattle and pig farms due to significant differences in crop composition. Crop production behaviour may differ between loamy and sandy soils.

Part-time farms are defined as farms, where the standard labour requirement per year is less than one full-time (1,665 hours) working year (cf. Danish Institute of Agricultural and Fisheries Economics, 1997a, p. 131). Full-time farms, where at least two thirds of the Standard Gross Margin are due to crop production are classified as crop farms, and analogously for cattle and pig farms[6]. Farms located in municipalities where more than 70 per cent of the area is loam are classified as loamy soil farms, and similarly for farms on sandy soil. Hence, farms from municipalities with less than 70 per cent of either loam or sand are not included in the data material used for econometric estimation.

Mean values of the key variables from the farm accounts data in the 8 distinguished farm categories are shown in table 3.1.

Some of the activity levels are aggregates of a group of activities. For instance, the spring barley area includes also rye and oats, the area with grass and greenfodder in rotation includes silage cereals, the number of dairy cattle is a weighted sum of dairy cows and rearing cattle, the number of beef cattle is a weighted sum of nurse cows and slaughtering calves, and the number of pigs is a weighted sum of sows and baconers (using Livestock Units as weights).

Cost shares represent the individual variable inputs' shares of total variable costs. Hence, the cost shares sum to one. The output/cost ratios represent the ratio between the revenue from a certain output and the total variable costs. For example, the revenue from spring barley production corresponds to 53.1 per cent of total variable costs. These ratios are used for calculating price elasticities referring to yield levels in chapter 5 below.

In addition to the variables represented in table 3.1, various proxy-variables have been considered in an attempt to adjust for differences in degree of specialisation, farm management skills, etc. in the econometric estimations.

[6] In addition, the group of pig farms include a minor share of farms, which are not specialised in one of the three categories – either because their production is relatively diversified, or because they specialise in other lines of production (e.g. poultry or furred animals).

Table 3.1. Mean values of farm data in eight different farm categories, 1973/74-1996/97

	Crop, loam	Crop, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Parttime, loam	Parttime, sand
Number of obs.	1490	1444	963	7528	932	2011	913	1410
Activity levels:								
Spring barley, ha	37.5	44.2	15.1	17.4	21.3	29.9	10.9	12.0
Winter barley, ha	1.1	1.1	0.4	0.2	3.2	1.7	0.4	0.1
Wheat, ha	31.0	10.2	4.1	1.4	15.4	7.6	4.1	1.6
Pulses, ha	3.8	4.6	0.4	1.1	1.8	3.7	0.3	1.0
Rape, ha	7.5	7.1	0.8	0.9	6.4	5.8	1.5	1.2
Potatoes, ha	0.2	6.9	0.0	0.5	0.1	1.3	0.0	0.7
Sugar beets, ha	13.5	0.4	2.4	0.1	1.9	0.1	2.3	0.0
Dairy cattle, cow equiv.	2.1	2.1	49.8	53.7	0.4	2.3	2.3	5.3
Beef cattle, calf equiv.	6.7	13.5	12.9	21.4	1.2	4.5	2.5	4.7
Pigs, sow equiv.	50.0	54.8	22.0	24.6	442.5	473.4	28.7	28.7
Poultry, stock dkr.	971.4	2497.0	855.1	291.5	6367.6	2664.3	470.6	136.5
Fodder beets, ha	0.0	0.4	3.5	5.4	0.1	0.3	0.2	0.7
Rot grass, ha	0.3	1.9	9.2	15.9	0.4	0.9	0.5	1.7
Perm grass, ha	1.5	3.2	4.1	6.1	0.6	1.7	0.5	1.3
Fallow, ha	1.3	1.2	0.2	0.4	1.2	1.5	0.1	0.2
Variable cost shares:								
Energy	0.055	0.055	0.030	0.030	0.036	0.035	0.038	0.039
Labour	0.507	0.512	0.488	0.474	0.346	0.338	0.553	0.540
Fertilisers	0.170	0.179	0.049	0.071	0.046	0.042	0.121	0.129
Pesticides	0.098	0.053	0.020	0.016	0.032	0.020	0.048	0.032
Services	0.042	0.056	0.044	0.050	0.025	0.025	0.075	0.085
Roughage	0.002	0.003	0.036	0.018	0.002	0.002	0.004	0.005
Conc feeds	0.126	0.142	0.333	0.341	0.513	0.538	0.161	0.170
Output/variable cost ratios[1]:								
Spring barley	0.531	0.560	0.170	0.161	0.196	0.197	0.631	0.637
Winter barley	0,010	0.010	0.004	0.001	0.020	0.008	0.013	0.004
Wheat	0.430	0.124	0.041	0.010	0.139	0.049	0.236	0.088
Pulses	0.035	0.052	0.002	0.007	0.013	0.019	0.013	0.038
Rape	0.087	0.083	0.007	0.006	0.051	0.034	0.083	0.068
Potatoes	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Sugar beets	0.004	0.000	0.000	0.000	0.000	0.000	0.001	0.000
Dairy cattle	0.020	0.012	0.640	0.593	0.002	0.013	0.016	0.042
Beef cattle	0.033	0.068	0.188	0.290	0.005	0.013	0.030	0.051
Pigs	0.044	0.057	0.018	0.020	0.243	0.273	0.057	0.046
Poultry	0.012	0.015	0.009	0.003	0.023	0.011	0.016	0.008

1. Output/variable cost ratios are defined as the revenue from a given commodity divided by total variable costs.

3.3. Economic data for individual lines of agricultural production

For the first two stages in the econometric estimation procedure (cf. section 2.3 above), the described data material suffices. However, in the third stage of econometric estimation (modelling adjustments in land allocation and capital and livestock intensity, cf. chapter 6 below) there is a need for data on the economic returns in different agricultural lines of production as a driving force for changes in activity levels.

Such data are not available at the individual level, but it is possible to construct data series for average changes in such sub-sector specific economic returns. The basis for such series is aggregate data on the economy in different agricultural sub-sectors, provided by the Danish Institute of Agricultural and Fisheries Economics (1997b). These data include revenues and costs per production unit (for example hectares or animal units) for the most important sub-sectors in Danish agriculture, including internal costs due to on-farm transfers between different sub-sectors.

An illustration of the data is given in table 3.2, where revenue and cost figures for 5 selected agricultural sub-sectors in 1995/96 are shown.

Table 3.2. Economic returns data for selected sub-sectors, 1995/96

	Spring barley	Wheat	Rape	Sugar beets	Dairy cows	Sows
	------------------- dkr/ha			---------------------	dkr/cow	dkr/sow
Revenue	7688	9782	6544	16589	15985	6985
Energy	145	176	147	310	175	165
Fertiliser	1019	1044	1209	1162	-501	-155
Pesticides	323	534	509	1612	-	-
Services	495	502	538	489	104	39
Feed	-	-	-	-	3037	3187
Gross margin	5706	7526	4141	13016	13170	3749
Calculated labour cost	1944	2171	1736	5191	5223	1689
Capital and other quasi-fixed costs	2747	3315	2623	5563	4861	2168
Net margin	1015	2040	-218	2262	3086	-108

Source: SJFI, series B

As mentioned above, such data are not available at the individual farm level. However, it may be presumed that changes over time in average economic return figures – as those shown in table 3.2 – will reflect changes in the economic return figures facing the individual farmers as well, although the general levels of economic returns per hectare or animal may differ among farms. Hence, we use the movements in average return figures as representatives for changes in the relative profitabilities between individual agricultural lines of production on the individual farms.

3.4. Using the data for econometric estimation

The farm account data are based on economic accounts from Danish farmers. Hence, the data provide a fairly holistic representation of farmers' actual economic behaviour, taking into account the possible interactions between different agricultural activities, use of different inputs etc. On the other hand, because the data have an economic focus, they are not very detailed in terms of physical quantities, e.g. amount of nitrogen fertilisers etc, which puts a limit to the level of detail in the interpretation of the econometric results.

Because farmers in general are present in the sample less than 10 subsequent years, the data material has its' relative strengths for econometric estimation in a static setting (although dynamic econometric analysis has also been carried out with the data, cf. chapter 6).

The large number of accounts and the panel characteristics of the database provides a good opportunity for econometric estimation of farmer behaviour at a microeconomic level. The large number of farms in the data material also provides the opportunity to study differences in behavioural parameters according to different farm characteristics, e.g. soil type, main production line, farm size, etc.

4. Estimation of conditional input demand equations

This chapter documents the specification and estimation of the system of variable input demand equations, i.e. step 1 in the overall estimation procedure outlined in section 2.3. In section 4.1, the derivation of the input demand equations is outlined, and the next two sections present the estimation methodology and results, respectively. The final section of the chapter provides an economic interpretation of the estimation results by transforming the estimated parameters into price elasticities.

4.1. Deriving demand equations on the basis of duality theory

A basic assumption in this step is that farmers are profit-maximizers. Hence, the farmers' optimisation problem is the following

(4-1) $$C(w,Y) = \min_x w \cdot x \qquad \text{s.t.} \qquad f(x) \geq Y$$

where $C(w,Y)$ denotes the cost function for the farm for given input price vector, w, and output vector, Y. f is the production function of the farm.

According to duality theory (cf. Chambers, 1988) a cost function satisfying certain characteristics (including linear homogeneity in prices, concavity in prices, and monotonically increasing in input prices etc.) represents economic behaviour consistent with a well-behaved production function (i.e. non-decreasing in inputs, concavity etc.). Hence, it is adequate to specify and estimate this cost function.

A normal approach in the empirical applications of duality theory is to use a flexible form approximation to this "true" cost function. In the following, we use the translog specification

(4-2) $$\ln C(w,Y) = \alpha_0 + \sum_{i=1}^{I} \alpha_i^* \ln w_i + \sum_{h=1}^{H} \beta_{Y_h}^* \ln Y_h + \tfrac{1}{2}\sum_{i=1}^{I}\sum_{j=1}^{I} \alpha_{ij}^* \ln w_i \ln w_j$$

$$+ \tfrac{1}{2}\sum_{h=1}^{H}\sum_{g=1}^{H} \beta_{Y_h Y_g}^* \ln Y_h \ln Y_g + \sum_{i=1}^{I}\sum_{h=1}^{H} \beta_{iY_h}^* \ln w_i \ln Y_h$$

where Y_h and Y_g are the levels of output h and g, respectively, and w_j is the price of input j. α and β are behavioural parameters, and asterisk indicates that the parameters represent a theoretical specification (as opposed to the empirical specification without asterisks below). Dual translog models of agricultural production behaviour have been estimated in various studies, e.g. Boyle & O'Neill (1990), Guyomard & Vermersch (1990).

The translog function can be assumed linearly homogenous in prices (i.e. only relative input prices matter) and symmetric in prices, implying

(4-3) $$\sum_{i=1}^{I}\alpha_i^* = 1; \sum_{i=1}^{I}\alpha_{ij}^* = 0; \sum_{i=1}^{I}\alpha_{iY_h}^* = 0 \quad and \quad \alpha_{ij}^* = \alpha_{ji}^*$$

Equations for variable input demands can be derived using Shepard's lemma (see e.g. Chambers, 1988), which states that the cost minimising demand for input i can be expressed as the derivative of the cost function with respect to the price of input i, i.e.

(4-4) $$x_i(w,Y) = \frac{\partial C(w,Y)}{\partial w_i}$$

where w_i is the price of input i. When the cost function is specified due to the translog form, the demand for input i, expressed in terms of input i's share of total costs, can be derived as

(4-5) $$S_i = \frac{w_i \cdot x_i(w,Y)}{C(w,Y)} = \frac{\partial \ln C(w,Y)}{\partial \ln w_i}$$
$$= \alpha_i^* + \sum_{j=1}^{I}\alpha_{ij}^* \ln w_j + \sum_{h=1}^{H}\alpha_{iY_h}^* \ln Y_h, i = 1,...,I$$

Thus, the i'th cost share is a linear function of logarithmic input prices and output levels. The econometric estimation of these equations is described and discussed in the remainder of this chapter.

4.2. Econometric estimation of input demand equations

For the purpose of econometric estimation, the following empirical version of the cost function (4-2) and corresponding cost-share equation system in (4-5) is specified

(4-6)

$$\ln C(w,Y) = \alpha_0 + \sum_{i=1}^{I}\alpha_i \ln w_{it} + \sum_{h=1}^{H}\alpha_{y_h} \ln y_{ht}^f + \sum_{h=1}^{H}\alpha_{z_h} \ln z_{ht}^f + \sum_{k=1}^{K}\alpha_{q_k} \ln q_{kt}^f$$
$$+ ½\sum_{i=1}^{I}\sum_{j=1}^{I}\alpha_{ij} \ln w_{it} \ln w_{jt} + \sum_{i=1}^{I}\sum_{h=1}^{H}\alpha_{iy_h} \ln w_{it} \ln y_{ht}^f + \sum_{i=1}^{I}\sum_{h=1}^{H}\alpha_{iz_h} \ln w_{it} \ln z_{ht}^f$$
$$+ ½\sum_{h=1}^{H}\sum_{g=1}^{H}\alpha_{y_h y_g} \ln y_{ht}^f \ln y_{gt}^f + \sum_{h=1}^{H}\sum_{g=1}^{H}\alpha_{y_h z_g} \ln y_{ht}^f \ln y_{zt}^f$$
$$+ ½\sum_{h=1}^{H}\sum_{g=1}^{H}\alpha_{z_h z_g} \ln z_{ht}^f \ln z_{gt}^f$$
$$+ \sum_{i=1}^{I}\sum_{k=1}^{K}\alpha_{iq_k} \ln w_{it} \ln q_{kt}^f + \sum_{h=1}^{H}\sum_{k=1}^{K}\alpha_{y_h q_k} \ln y_{ht}^f \ln q_{kt}^f + \sum_{h=1}^{H}\sum_{k=1}^{K}\alpha_{z_h q_k} \ln z_{ht}^f \ln q_{kt}^f$$
$$+ ½\sum_{k=1}^{K}\sum_{k=1}^{K}\alpha_{q_k q_k} \ln q_{kt}^f \ln q_{kt}^f + v_C^f + u_{Ct}^f$$

(4-7)

$$S_{it}^f = \alpha_i + \sum_{j=1}^{I}\alpha_{ij} \ln w_{jt} + \sum_{h=1}^{H}\alpha_{iy_h} \ln y_{ht}^f + \sum_{h=1}^{H}\alpha_{iz_h} \ln z_{ht}^f + \sum_{k=1}^{K}\alpha_{iq_k} \ln q_{kt}^f$$
$$+ v_i^f + u_{it}^f, \quad i = 1,\ldots,I$$

The output variable Y_h has been split up into a yield level variable, y_h, and an activity level variable, z_h. This split provides the opportunity to distinguish the effects on input demands due to yield and activity level changes, respectively. The idea behind the two-dimensional representation of output levels (in activity levels and yield levels, respectively) is that it enables explicit modelling of the output determination in these two dimensions, cf. chapters 5 and 6 below. The variables q_k represent other relevant explanatory variables. Subscript t indexes time-periods and f indexes farms. u_{Ct}^f and u_{it}^f are white noise by assumption, and υ_C^f and υ_i^f represent a (one-way) error component representing the diversity among farms. This specification of the system of demand functions takes advantage of the panel nature of the data (cf. Hsiao, 1991 and Baltagi, 1995), and provides overall estimates of the slope parameters.

The set of price variables (w) includes the prices of energy, labour, fertilisers, pesticides, services, purchased roughage, cattle feed, pig feed and poultry feed. Activity variables (z) include activity levels (numbers of hectares or livestock units) in the model's 15 lines of production, , yield variables (y) are represented by yield levels (per hectare or animal) in 11 lines of marketed production, and other explanatory variables (q) include equipment, buildings, trend variable and various proxy variables for farmer's efficiency.

The system of cost shares equations specified in (4-7) is the set of equations to be estimated in the following. The system consists of I one-way error component equations[7] (Baltagi, 1995). Since these equations include both a white noise error-term, u_{it}^{f}, and a systematic error component representing farm differences, v_{i}^{f}, Ordinary Least Squares (OLS) cannot be used to estimate the parameters of these models. If, on the other hand, the variance-covariance matrix for the whole system of equations is known, (4-7) can be estimated using a Generalized Least Squares (GLS) estimator. This variance-covariance matrix is not known, but the problem is overcome using a Feasible Generalized Least Squares (FGLS) method. The cost share equations are estimated using a panel data application of Iterative Seemingly Unrelated Regressions (ITSUR) first proposed by Avery (1977) and further discussed in Baltagi (1995). The applied estimation procedure allows for unbalanced panel data sets and is therefore well suited for our purpose since it embeds both the panel nature of the data used and the system nature of equation (4-7) in the estimation[8]. The outset of this estimation procedure is the OLS estimates of the parameters in each of the I within-transformed[9] equations separately (cf. Baltagi, 1980). From this outset the procedure iterates, calculating the FGLS estimates of the parameters of the whole system in each iteration, until convergence is reached and the minimum weighted sum of squared residuals in the I cost equations is obtained. Hence, we obtain an Iterative FGLS estimator of the parameters in (4-7).

To assess the validity of the estimates obtained using the Iterative FGLS we test for multicollinearity, heteroscedasticity as well as serial correlation. We use single-equation diagnostics for each of the demand equations. The Breusch-Pagan[10] test statistic is used to test for heteroscedasticity.

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[7] The one-way error component represents the inter-farm variation. Alternatively, a two-way model could be specified in which both a farm specific error-component and a time specific error-component were included in each equation of the model. For further on this, see Hsiao (1991) or Baltagi (1995).

[8] For the ITSUR-estimation we extend the ITSUR-procedure coded for GAUSS by Parke Wilde and posted on the internet (cf. http://gurukul.ucc.american.edu/econ/gaussres/regress/regress.htm). Parke Wilde's procedure hinges on the exact same set of right-hand-side variables in all equations. Our extension of the procedure consists of allowing for different sets of right-hand-side variables in the I equations.

[9] i.e. formulated in terms of individual mean corrected variables

[10] see Breusch and Pagan (1979) or Johnston (1984)

(4-8) $$\frac{ESS_{\varepsilon^2,w,y,z,k}}{2} \sim \chi^2(I+2H-1)$$

where $ESS_{\varepsilon^2,w,y,z,k}$ represents the explained sum of squares from an auxiliary regression of the squared residuals from the estimated equation on the equation's explanatory variables.

To test for first order serial correlation we use a Generalized Durbin-Watson test statistic due to Bhargava et al. (1982), given by

(4-9) $$\frac{\sum_{f=1}^{F}\sum_{t=2}^{T_f}\left(\tilde{u}_{it}^{f}-\tilde{u}_{it-1}^{f}\right)^2}{\sum_{f=1}^{F}\sum_{t=2}^{T_f}\tilde{u}_{it}^{f\,2}}$$

where $\tilde{u}_{it}^{f}$ is the estimated residual from the estimation of expression (4-7), F is the total number of farms in the dataset and T_f is the number of time periods that farm f is included in the dataset. This means that the tester in (4-9) allows for unbalanced datasets and it is, therefore, essentially a generalization of the traditional Durbin-Watson test statistic from pure time series data to the panel data case (cf. Bhargava et al., 1982)[11].

4.3. Estimation results

In the following, some results of the econometric estimation are discussed. A few examples of the estimated parameters are extracted in table 4.1, whereas complete estimation results are presented in Appendix B.

The parameters in a given cost share equation derived from the translog cost function above express the change in the considered cost share, due to a change in the respective explanatory variables. For example, if the price of energy increases by one per

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[11] As an alternative to the Generalized Durbin Watson, the Linear Correlation Coefficient proposed by Verstegen et al. (1995) could be considered. However, as this coefficient seems to be negatively biased when T_f is small for a large number of farms, this statistic is of small use in the current context.

cent, energy's share of variable costs will increase by 0.0356/100 for crop farms on loamy soils, whereas a one per cent increase in the wage rate will decrease energy's share of variable costs by 0.0348/100.

Table 4.1. Selected estimation results

Farm type:	Crop, loam	Crop, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Part-time, loam	Part-time, sand
Energy share:								
Energy price	0,0356	0,0437	-0,0177	0,0154	0,0217	0,0254	0,0105	0,0223
Wage rate	-0,0348	-0,0341	-0,0165	-0,0160	-	-0,0070	-0,0329	-0,0225
Fertiliser price	0,0123	-	0,0147	0,0086	-	-0,0085	0,0272	0,0080
Labour share,								
Wage rate	0,2597	0,1698	0,1473	0,1766	0,1989	0,2069	0,1280	0,1665
Fertiliser price	-0,0510	-0,0541	-0,0242	-0,0429	-0,0148	-0,0144	-0,0365	-0,0772
Pesticide price	-0,0767	-0,0550	-0,0316	-0,0239	-0,0274	-0,0144	-0,0226	-
Fertiliser share:								
Fertiliser price	0,0420	0,0502	0,0157	0,0333	0,0405	0,0340	0,0196	0,0544
Wage rate	-0,0510	-0,0541	-0,0242	-0,0429	-0,0148	-0,0144	-0,0365	-0,0772

In most cases, the estimated parameters exhibit similar patterns across farm types, in that their signs and magnitudes are similar for different farm types. Thus, it seems reasonable to consider the same type of model for all farm types. The tables in appendix B contain only the significant parameters in the estimation. Furthermore, parameters that were only significant at the 5 or 10 per cent level, respectively, are marked in the tables.

Table 4.2 shows some diagnostics for the individual equations on the eight farm types. Although the reliability of the diagnostics may be discussed, they provide some indication of the validity of the estimation results. R^2 (full) is the multiple coefficient of correlation, when the explanatory power of the individual constant terms are taken into account, whereas R^2 (partial) is the multiple coefficient of correlation, when this effect is not accounted for. Hence, in general R^2 (full) exceeds R^2 (partial). For most of the estimated equations, these statistics are satisfactory, keeping in mind the data material, which is characterised by a large number of farms, but relatively few observations per farm.

Table 4.2. Statistical performance of the estimated equations

		Energy share	Labour share	Fertiliser share	Pesticide share	Services share	Roughage share
Crop, loam	R^2 (full)	0.639	0.774	0.713	0.697	0.893	0.794
	R^2 (partial)	0.215	0.315	0.388	0.367	0.182	0.218
	GDW	2.033	2.029	2.036	1.927	2.095	2.178
	Breusch-Pag.	0.023	0.260	0.110	0.167	0.136	0.051
Crop, sand	R^2 (full)	0.697	0.794	0.773	0.670	0.799	0.678
	R^2 (partial)	0.238	0.239	0.337	0.270	0.215	0.069
	GDW	2.110	1.936	2.016	1.940	1.777	2.101
	Breusch-Pag.	0.037	0.156	0.126	0.273	0.375	0.027
Cattle, loam	R^2 (full)	0.745	0.866	0.807	0.676	0.851	0.739
	R^2 (partial)	0.282	0.304	0.254	0.236	0.124	0.124
	GDW	1.986	1.997	2.075	2.078	1.967	1.899
	Breusch-Pag.	0.003	0.058	0.028	0.017	0.025	0.187
Cattle, sand	R^2 (full)	0.638	0.754	0.673	0.604	0.713	0.532
	R^2 (partial)	0.304	0.411	0.304	0.358	0.221	0.107
	GDW	1.965	1.997	1.972	1.996	1.966	1.985
	Breusch-Pag.	0.017	0.388	0.219	0.114	0.176	0.837
Pigs, loam	R^2 (full)	0.745	0.801	0.715	0.641	0.735	0.562
	R^2 (partial)	0.229	0.338	0.405	0.324	0.073	0.083
	GDW	2.064	1.962	1.990	2.002	1.929	2.034
	Breusch-Pag.	0.003	0.168	0.046	0.038	0.053	0.075
Pigs, sand	R^2 (full)	0.731	0.827	0.785	0.676	0.788	0.487
	R^2 (partial)	0.194	0.415	0.477	0.286	0.177	0.061
	GDW	1.959	2.002	1.969	2.035	1.979	2.029
	Breusch-Pag.	0.006	0.165	0.038	0.023	0.023	0.028
Part-time, loam	R^2 (full)	0.670	0.789	0.724	0.752	0.859	0.777
	R^2 (partial)	0.156	0.222	0.320	0.242	0.203	0.294
	GDW	1.896	1.967	1.873	2.014	2.004	2.215
	Breusch-Pag.	0.021	0.060	0.126	0.105	0.140	0.033
Part-time, sand	R^2 (full)	0.642	0.746	0.753	0.595	0.737	0.677
	R^2 (partial)	0.179	0.234	0.526	0.238	0.242	0.199
	GDW	1.980	2.061	1.854	1.965	2.028	2.007
	Breusch-Pag.	0.065	0.233	0.248	0.297	0.389	0.072

Note: Breusch-Pagan statistics denote the probability of residuals being homoscedastic.

For the first order serial correlation to be negligible the GDW-testor must be close to 2. Therefore, the GDW shows no severe problems with first order serial correlation. The Breusch-Pagan statistic showed signs of heteroscedasticity in most equations. Further investigation showed that the heteroscedasticity is due to a farm-size effect – variance is higher for small farms than for large farms. In an attempt to take care of this in the estimation procedure further variables were included in the equations[12]. This was, however, not enough to eliminate heteroscedasticity completely.

In Kristensen & Jensen (1999), the fertiliser cost share equation was estimated as a single-equation estimation for the eight farm types. The overall characteristics of the findings in the present study concerning parameter signs and magnitudes in the fertiliser cost share equation are quite similar to those in the single-equation study, and so is the statistic performance of the fertiliser cost share equation.

4.4. Interpreting the estimation results in terms of elasticities

Direct economic interpretation of coefficient estimates in the translog cost function is difficult. However, the estimated coefficients can be transformed into price elasticities, which have a more straightforward economic interpretation. Hence, from the estimated cost share equations, expressions for "Hicksian"[13] own-price and cross prices elasticities can be derived as (see e.g. Sidhu & Banaante, 1981):

(4-10) $$\varepsilon_{ii} = \frac{\partial x_i}{\partial w_i} \cdot \frac{w_i}{x_i} = \frac{\alpha_{ii}}{S_i} + S_i - 1$$

(4-11) $$\varepsilon_{ij} = \frac{\partial x_j}{\partial w_i} \cdot \frac{w_i}{x_j} = \frac{\alpha_{ij}}{S_j} + S_i$$

Using these expressions and the estimated coefficients, we can obtain estimates of the output compensated (Hicksian) price elasticities at the farm level. Such elasticities, evaluated at the mean values of all the model's variables for each of the eight farm groups in the model are given in table 4.3.

[12] The residuals turned out correlated with Standard Gross Margin^{-1} and Standard Gross Margin$^{-½}$, respectively. Therefore these variables where included on the right-hand-side of the equation. The results are shown in the appendix.

[13] i.e. output-compensated, thus representing the pure input composition effect.

Table 4.3.	Hicksian average own- and cross-price elasticities for all eight farm groups						
	Energy	Labour	Fertiliser	Pesticide	Service	Roughage	Conc. feeds
Energy price	-0,3708 (0,1612)	-0,0270 (0,1939)	0,3098 (0,3118)	0,0121 (0,0424)	0,0503 (0,0214)	-0,0091 (0,0488)	0,0374 (0,1655)
Wage rate	-0,0009 (0,0181)	-0,1244 (0,0817)	0,0211 (0,0386)	-0,0271 (0,0311)	0,0503 (0,0214)	0,0090 (0,0123)	0,1012 (0,1168)
Fertiliser price	0,1116 (0,1513)	0,0402 (0,1297)	-0,4439 (0,2393)	0,2056 (0,1067)	0,0503 (0,0214)	0,0555 (0,0886)	-0,0115 (0,1537)
Pesticide price	0,0134 (0,0509)	-0,1232 (0,6592)	0,3878 (0,3560)	-0,8373 (0,1256)	-0,0111 (0,1605)	0,1577 (0,2799)	0,5012 (0,3591)
Service price	0,0399 (0,0097)	0,4697 (0,0828)	0,1009 (0,0564)	0,0169 (0,0735)	-0,2671 (0,4771)	-0,0318 (0,1355)	-0,2111 (0,3956)
Roughage price	0,0100 (0,0885)	0,4697 (0,0828)	0,7814 (1,0271)	0,2861 (0,4263)	-0,6220 (2,2525)	-0,7332 (1,1493)	0,5928 (0,5488)
Concentrate feed price	-0,0269 (0,0664)	0,0401 (0,1659)	-0,0633 (0,1402)	0,1061 (0,1717)	-0,0165 (0,1154)	0,0753 (0,2190)	-0,2073 (0,1909)

The price elasticities shown in table 4.3 represent the adjustments in input compositions due to changes in relative input prices. An underlying premise for the elasticities is that production in the different agricultural sub-sectors (i.e. yield and activity levels in all sub-sectors) is unchanged. Hence, the elasticities have a Hicksian interpretation, in that they represent the pure input substitution effect of changed input prices. The complete set of estimated output compensated input price elasticities for the eight farm groups is given in appendix D.

In table 4.3, standard deviations are shown. These standard deviations represent the variation between the 8 farm groups. In general, the patterns of substitution are fairly similar in different farm groups, although there are differences. For example, the own-price elasticity for labour lies in the interval –0.2 - -0.1 for all farm groups, except crop farms on loamy soil, and the own-price elasticity for purchased fertilisers lies around -0.5 for all farm groups except pig farms. The estimated own-price elasticity estimates for fertilisers on pig farms are close to zero. This may be surprising, as these elasticities represent the demand for commercial fertilisers, which is marginal in the total fertilisation on pig farms and thus could be expected to be fairly sensitive. On the other hand, if commercial fertilisers only represent a minor share of total costs, the use of these fertilisers may be a minor consideration on pig farms, and hence these farms may not care much about the fertiliser price. For most farm groups, labour and energy are substitutes, but for pig farms they are complements.

The precision of price elasticities for the individual farm categories can be evaluated by approximating the elasticities' variances, using a first order Taylor series expansion to the price elasticity expressions

$$\text{(4-12)} \qquad \sigma^2_{\varepsilon_{ij}} \approx \left[\frac{\partial\varepsilon_{ij}}{\partial\alpha_{ij}}, \frac{\partial\varepsilon_{ij}}{\partial S_i}, \frac{\partial\varepsilon_{ij}}{\partial S_j}\right] \cdot \begin{bmatrix} \sigma^2_{\alpha_{ij}} & \sigma_{\alpha_{ij},S_i} & \sigma_{\alpha_{ij},S_j} \\ \sigma_{\alpha_{ij},S_i} & \sigma^2_{S_i} & \sigma_{S_i,S_j} \\ \sigma_{\alpha_{ij},S_j} & \sigma_{S_i,S_j} & \sigma^2_{S_i} \end{bmatrix} \cdot \begin{bmatrix} \partial\varepsilon_{ij}/\alpha_{ij} \\ \partial\varepsilon_{ij}/S_i \\ \partial\varepsilon_{ij}/S_j \end{bmatrix}$$

Assuming that the off-diagonal elements in the variance-covariance matrix are zero, and using the error term variances in the respective cost share equations as estimates for $\sigma^2_{S_i}$ and $\sigma^2_{S_j}$, the elasticity variances can be approximated as

$$\text{(4-12')} \qquad \sigma^2_{\varepsilon_{ij}} \approx \left(\frac{1}{S_i}\right)^2 \cdot \sigma^2_{\alpha_{ij}} + \left(-\frac{\alpha_{ij}}{S_i^2}\right)^2 \cdot \sigma^2_{S_i} + \sigma^2_{S_j}$$

In appendix D, standard deviations (i.e. square roots of the variances) are presented for each individual elasticity at the farm group level.

The econometric estimations described in this chapter lead to short-run elasticities of input demands for 8 farm groups. In general, the results seem satisfactory from statistical as well as economic viewpoints. The estimated elasticities represent the pure input substitution effects, because yield levels in different sub-sectors as well as the composition of agricultural activities are assumed constant in the calculation of the elasticities.

In the econometric estimation, parameters related to the yield and activity levels in different agricultural sub-sectors are estimated. These parameters represent the change in cost shares of a relative change in the specific yield or activity levels. For example, the coefficients related to the yield level in wheat production represent the wheat yield effect on input composition, and the coefficients related to the wheat area represent the wheat area effect on the farm group's input composition. As we will see in the next chapter, these parameters also play a role in determining the optimal production intensity.

5. Equations for profit maximising crop yield levels

The translog cost function outlined in chapter 4 provides a description of variable input demands, considering yields and activity levels as exogenous variables. Derivation and estimation of these input demand relations are described in chapter 4, thus completing the first step of the estimation procedure outlined in chapter 2. The present chapter describes the second step in the procedure, which builds on the results from chapter 4.

5.1. Equations for profit maximising yield levels

A cost function represents the use of variable inputs for given prices, output levels etc. However, a cost function can also provide the basis for determining yield levels, assuming that farmers exhibit profit maximising behaviour. A condition for profit maximising yield levels for farmers in a competitive economic environment is that the marginal costs of output equals the price of the considered output. In the translog cost function case, this can be stated formally for sub-sector h by differentiating expression (4-2)

(5-1)

$$p_h = \frac{\partial C}{\partial Y_h} = \frac{\partial \ln C}{\partial \ln Y_h}\frac{C}{Y_h}$$
$$\Downarrow$$
$$S_{y_h} = \frac{p_h \cdot Y_h}{C} = \frac{\partial \ln C}{\partial \ln Y_h} = \alpha_{Y_h} + \sum \alpha_{iY_h} \ln w_i + \sum_g \beta_{Y_g Y_h} \ln Y_g$$

An interpretation of expression (5-1) is given in figure 5.1. The C_0-curve represents a cost function - the costs of varying the output in subsector h, Y_h (which equals the activity level in sub-sector h, z_h, multiplied by the output yield per activity unit, y_h) holding all other activity and yield levels constant. Assuming that activity levels (numbers of hectares or animals) are fixed, the C_0-curve thus represents the partial cost implications of varying the yield level in sub-sector h[14]. Given the assumption of profit maximisation, the inverse slope of the C_0-curve (the marginal cost) equals the output price p_h, and changes in p_h will imply movements along the C_0-curve in order to maintain equilibrium between output price and marginal cost.

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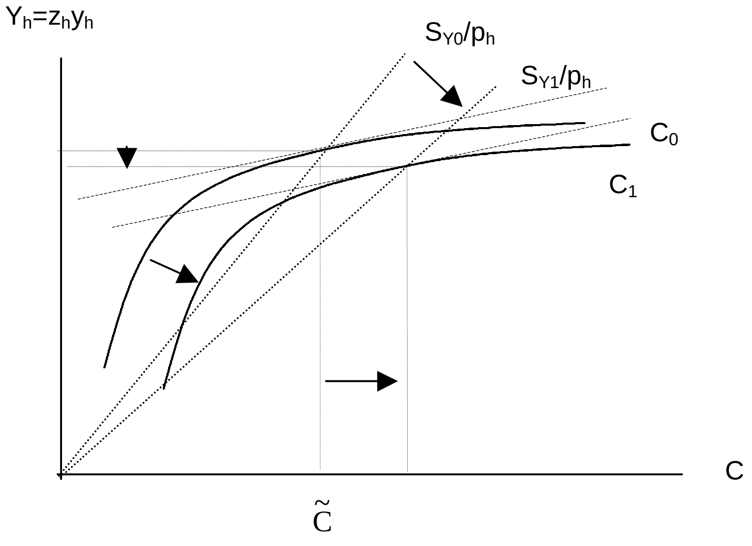
[14] please note that the costs are measured along the horizontal axis.

Changes in variables which serve as arguments in the cost function (e.g. input prices) will imply shifts in the C-curve, as illustrated by the shift from C_0 to C_1 in figure 5.1. Such a shift may lead to an increase or a decrease in the secant slope (given by the S_{yh}/p_h-ratio, which also represents changes in the output-cost ratio for given output price p_h), depending on the location of the new tangency point (where marginal cost equals output price) to the left or right of $\tilde{C}$, which again depends on the curvature of the cost function.

If for example, an input price increase does not affect the curvature of the cost function significantly, as is the case in figure 5.1, the price increase will tend to reduce S_{Yh} (and hence the secant slope S_{Yh}/p_h), whereas if the curvature changes dramatically due to the price change (e.g. the C-curve in figure 5.1 becomes "more flat") an increase in S_{Yh} may occur.

The tangent slope in the figure is given by the inverse output price, $1/p_h$. In the illustrated example, the output price is assumed unchanged, represented by identical tangent slopes to the two C-curves.

Figure 5.1. Graphical illustration of yield level optimisation from a cost function



Assuming exogenous activity levels in all lines of production, expression (5-1) implies that the marginal cost related to the respective yield levels equal the corresponding output prices – a percentage change in yield level for sub-sector h is equal to the percentage change in total output from sub-sector h, if the activity level of that sub-sector remains unchanged. This allows us to derive the output-cost ratio equations from a more general specification of the cost function,where total output from a sub-sector is represented by the combination of an activity variable and a yield variable. Differentiation the empirical cost function specified in expression (4-6) yields the output-cost ratio equation for sub-sector h for farm f:

(5-2) $$S^f_{y_h t} = \alpha^f_{y_h} + \sum \alpha_{iy_h} \ln w_{it} + \sum_g \alpha_{y_g y_h} \ln y^f_{gt} + \sum_g \alpha_{z_g y_h} \ln z^f_{gt} + \sum_k \alpha_{q_k y_h} \ln q^f_{kt} + \varepsilon^f_{y_h t}$$

The set of explanatory variable is identical to that of expression (4-7). In addition, the equations in expression (5-2) include a fixed effect parameter, $\alpha^f_{y_h}$, representing differences in individual levels due to differences in e.g. skills, management etc.

As is the case with variable cost share equations, the derived system of yield equations is subject to certain symmetry restrictions. First, there are symmetry conditions related to some of the parameters in the input demand equations. Thus, the coefficient to yield variable y_h in the demand equation for input i (S_i) should equal the coefficient to price variable w_i in the equation for S_{y_h}, i.e. $\alpha_{iy_h} = \alpha_{y_h i}$. Secondly, there is a symmetry condition between different yield levels. Hence, the coefficient to yield variable g in the equation for S_{y_h} should equal the coefficient to yield h in the equation for S_{y_g}, i.e. $\alpha_{y_h y_g} = \alpha_{y_g y_h}$. This corresponds to the condition that partial elasticities of transformation between two inputs are the same, irrespective of which of these output prices are changed.

5.2. Econometric estimation of the derived yield equations

In principle, the yield equations derived above forms a set of SUR-equations and hence could be estimated using a methodology similar to that used for the cost share equations in the previous chapter. Estimation of the yield equations could even be incorporated in the estimation of the cost share equations, thus taking into account the interactions between the parameters in the cost share and yield equations, respectively. However, two problems imply that such a procedure has not been applied in the current context.

First, the profit maximisation assumption represented in the above yield equations is more restrictive than the cost minimisation assumption underlying the cost share equations. Thus, if the profit maximisation assumption is too restrictive, a simultaneous estimation of both yield and cost share equations will lead to distorted estimates of both types of equations. On the other hand, a stepwise estimation procedure (estimating the cost share equations in the first step and the yield equations in the second step, conditional on parameters estimated in the first step) will ensure that parameters in the cost share equations are not distorted by the profit maximisation assumption, while at the same time being consistent with this assumption.

Second, not all lines of production are represented on all farms in the data material. Hence, data on yield levels for individual sub-sectors do not exist for all observations. Whereas non-existing activity levels in a sub-sector can be represented by zeros in the set of explanatory variables, this does not make sense for yield levels. Instead, observations with non-existing activities within the specification are deleted from the data set underlying the considered equation. For example, when estimating a yield equation for spring barley where different crop yield levels are among the explanatory variables, all the applied observations must contain non-zero activity levels in all lines of production reflecting these explanatory crop yield levels.

As very few farms have positive activity levels in all lines of production, a model specification with all yield levels among the explanatory variables would lead to deleting almost all observations from the dataset before estimating. Thus, the yield level models are restricted in the sense that y_h is the only yield level variable in the expression for S_{yh}.

For example, the wheat yield level is not an explanatory variable in the yield equation for spring barley. This implies that the spring barley yield equation can be estimated on all observations with positive spring barley production, the wheat yield equation can be estimated on all observations with positive wheat production, etc.

Due to these deletions of observations in the estimation procedure, the lenghts of the data sets used for estimating the different yield equations differ. This complicates the estimation within e.g. a simultationeous equations estimation framework. Consequently, the above yield equations are estimated as single equations, conditional on the parameters estimated in the first step. It should be noted that if the error terms, $\varepsilon^{f}_{y_h t}$, in expression (5-2) are contemporaneously correlated between different yield equations, the estimators do not exhibit maximum efficiency, because such correlation is not taken into account.

Data for output shares represent expected shares in the sense that farmers are assumed to perfectly foresee the actual crop prices, which may be reasonable due to more or less guaranteed price system within the Common Agricultural Policy, etc. Experiments with myopic expectations have also been attempted, however with less success.

Yield levels for cash crops can straightforwardly be represented by crop yields in kg per hectare for the respective crops. Yield data have been adjusted for climatic variations by constructing two climate correction indices – for loamy and sandy soils, respectively. These indices have been constructed using experimentally based crop yield functions (describing the relationship between application of nitrogen and crop yield) and price data. Using the crop yield functions and the price data, standardised (adjusted for climatic effects) yield levels can be calculated, and the climate index can be calculated as the ratio between observed and standardised yield levels. In order to remedy some problems of heteroskedasticity, two auxiliary variables were included – the reciprocal of the Standard Gross Margin (INVSDB) and the square root of the reciprocal of the Standard Gross Margin (INVSQSDB).

The estimated equations are tested using the same diagnostics as the estimated cost share equations described in chapter 4.

5.3. Econometric estimation results

The econometric estimation procedure discussed above leads to estimates of the α-coefficients in the above specification. As mentioned above, there is a symmetry relation between input price parameters in the considered output/cost ratio equations and yield level parameters in the cost share equations estimated in chapter 4. Hence, the input price parameters in the current equations are considered to be predetermined.

Unfortunately, results from straightforward estimation of the remaining parameters led to results which were in conflict with a priori knowledge in terms of unexpected signs and magnitudes, e.g. in relation to the own-yield effects of crop price changes. For these parameters, a priori information exists in terms of estimated relations between fertiliser input and individual crop yield levels based on field experiments. For example, this leads to a priori estimates of the partial cross-price elasticity between fertiliser price and yield level (Rude, 1991). In order to take such information into account, a restricted estimation was conducted in which the respective $\alpha_{y_h y_h}$-coefficients were considered predetermined in order to ensure consistency with such cross-price elasticities. It is further assumed, that the own-price yield effects in the livestock sectors are very small (elasticities at 0.001) Although most relevant coefficients thus are predetermined, the estimation is still interesting because of the possibility for econometric tests of the estimated equations, as well as the possibility for calculating the yield effects of other inputs than fertilisers.

In the following, the results are discussed briefly by means of an example, whereas detailed results are given in appendix C. For example, consider some of the estimated coefficients from the wheat yield equation for crop farms on loamy soil. These are given in table 5.1.

Table 5.1. Estimated coefficients for wheat yield equation on crop/loam farms

Explanatory variables	Coeff.	St. Dev.
Prices:		
Fertiliser	-	
Pesticide	0,0020	0,0008
Services	-0,0022	0,0007
Pig feed	-0,2092	0,0865
Cattle feed	-0,2585	0,0829
Poultry feed	0,4562	0,1005
Activity levels:		
Wheat	0,3151	0,0106
Perm. grass	-0,0053	0,0020
Beef cattle	-0,0062	0,0025
Pigs	-0,0076	0,0021
Yield levels:		
Wheat	1,8087	-
Other variables:		
Economic size	-0,4503	0,1165
Equipment	0,0339	0,0128
Crop share	0,5526	0,0939
Farmer's age	-0,0019	0,0010
Linear trend	-0,0208	0,0030
Climate	-	-
Efficiency proxy 1	-0,0069	0,0025
Efficiency proxy 2	0,0005	0,0001
INVSDB	11094,6	5780,2
INVSQSDB	-218,7	108,4

The input price coefficients were predetermined for the current estimation (cf. chapter 4) due to the imposed symmetry condition, and the own-yield coefficient was also pre-determined, cf. above. The remaining coefficients have been estimated in the current estimation step.

In terms of figure 5.1, the coefficients can be interpreted as follows. For instance, if the price of services goes up, the C-curve moves to the right – costs will increase. As the price coefficient is negative (cf. table 5.1), this will reduce the output-cost ratio S_y and thus the secant slope in figure 5.1 – variable costs will decrease relatively less than the yield level. Consequently, the optimal wheat yield level will decrease relative to the variable costs due to the price increase.

As another example, consider pesticides. If the price of pesticides goes up, the C-curve will again shift to the right, but according to the positive price coefficient, the output-cost ratio S_y (and hence the secant slope) will increase in this case. An input price increase will trigger an adjustment in yield level, which in turn reduces variable costs more than proportional to the yield adjustment. In terms of figure 5.1, the new tangency point of output price and marginal cost is situated to the left of the "old" secant. Thus, a positive coefficient reflects a relatively strong adjustment in profit maximising input use due to a change in optimal yield level (i.e. a relatively flat crop yield curve).

An increase in the yield level for wheat implies a movement along the C_0-curve to the right, and an increase in marginal costs. Such a movement can only be optimal if the increase in marginal costs is reflected in a corresponding crop price increase. Hence, the point of tangency also moves to the right in figure 5.1, and the secant slope decreases. The sign of the estimated yield level coefficient determines the resulting change in the output-cost ratio. In the case of wheat, a profit maximising one per cent increase in the wheat yield level leads to an increase in the output-cost ratio for wheat of 0.0181 (or 4.2 per cent when compared with the average of 0.430, cf. table 3.1). As variable costs increase due to a yield increase, this implies a wheat price increase of more than 3.2 per cent is necessary, if a one per cent yield increase should be profit maximising.

Table 5.2 presents diagnostics concerning the statistical performance of the estimated output/cost ratio equations. R^2 (full) represents the goodness-of-fit taking into account the contributions from the farm-specific constant terms, whereas R^2 (partial) represents the goodness-of-fit, when these contributions are not included. In general, the equations (including constant terms) explain between 70 and 85 per cent of total variation, and without constant terms between 50 and 70 percent. This is considered to be satisfactory. Only in a few cases, heteroscedasticity could not be rejected, according to the applied Breusch-Pagan statistic.

Table 5.2. Statistical performance of the estimated equations

	Crop, loam	Crop, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Parttime, loam	Parttime, sand
Spring barley								
R^2 (full)	0.74	0.81	0.83	0.78	0.78	0.77	0.81	0.75
R^2 (partial)	0.60	0.61	0.66	0.54	0.54	0.56	0.56	0.61
B-P	0.99	1.00	1.00	1.00	0.00	0.00	1.00	1.00
Winter barley								
R^2 (full)	0.92	0.76	-	0.84	0.90	-	-	-
R^2 (partial)	0.70	0.57	-	0.71	0.69	-	-	-
B-P	0.97	0.82	-	0.73	1.00	-	-	-
Wheat								
R^2 (full)	0.86	0.85	0.75	0.76	0.72	0.73	0.87	0.83
R^2 (partial)	0.55	0.61	0.67	0.61	0.55	0.65	0.58	0.53
B-P	0.95	1.00	0.00	1.00	0.88	0.41	0.00	0.91
Pulses								
R^2 (full)	0.57	0.64	-	0.61	0.78	0.69	0.66	0.69
R^2 (partial)	0.57	0.66	-	0.73	0.70	0.71	0.62	0.69
B-P	1.00	0.00	-	1.00	1.00	1.00	0.68	0.76
Rape								
R^2 (full)	0.81	0.69	0.70	0.72	0.69	0.71	0.78	0.79
R^2 (partial)	0.62	0.54	0.73	0.62	0.52	0.63	0.64	0.50
B-P	0.77	0.80	0.36	0.98	0.22	0.00	0.04	1.00
Potatoes								
R^2 (full)	-	0.90	-	0.84	-	0.87	-	-
R^2 (partial)	-	0.63	-	0.47	-	0.50	-	-
B-P	-	0.08	-	0.00	-	0.92	-	-
Sugar beets								
R^2 (full)	0.82	0.83	0.83	-	0.80	-	0.74	-
R^2 (partial)	0.53	0.75	0.57	-	0.70	-	0.53	-
B-P	0.75	0.85	0.00	-	0.98	-	0.00	-
Milk								
R^2 (full)	0.94	0.71	0.90	0.92	-	0.93	-	0.95
R^2 (partial)	0.51	0.64	0.63	0.70	-	0.50	-	0.71
B-P	0.89	0.41	0.99	1.00	-	0.00	-	0.12
Beef								
R^2 (full)	0.88	0.82	0.83	0.81	0.96	0.85	0.80	0.78
R^2 (partial)	0.45	0.51	0.59	0.58	0.67	0.44	0.55	0.55
B-P	0.00	0.65	0.00	1.00	0.00	0.00	0.00	0.00
Pigs								
R^2 (full)	0.96	0.86	0.75	0.78	0.87	0.73	0.87	0.83
R^2 (partial)	0.58	0.47	0.81	0.62	0.42	0.46	0.59	0.63
B-P	0.71	0.99	0.38	1.00	1.00	0.91	0.10	0.87
Poultry								
R^2 (full)	0.97	0.85	0.97	0.85	0.98	0.99	0.97	0.89
R^2 (partial)	0.18	0.66	0.37	0.57	0.68	0.04	0.25	0.33
B-P	0.00	1.00	0.00	1.00	0.53	0.00	0.00	0.00

Note: Breusch-Pagan (B-P) statistic denotes the probability of residuals being homoscedastic

5.4. Interpreting the estimation results in terms of elasticities

It is clear from this discussion, that the quantitative effects on yield levels are not evident from the estimated coefficients. As was the case with coefficients of the cost share equations, the estimated coefficients in the yield equations can however be transformed into price elasticities, expressing the percentage yield response to percentage changes in various prices, including the output price, utilising the condition of equality between output price and marginal costs.

From the equilibrium condition for optimal yield level (5-1) and the input demand functions in chapter 4, expressions for price elasticities of yield levels with respect to input and output prices, as well as elasticities of input demands with respect to output prices can be derived as

$$\varepsilon_{hh} = \frac{\partial y_h}{\partial p_h} \cdot \frac{p_h}{y_h} = \frac{S_{y_h}}{\alpha_{y_h y_h} + S_{y_h}(S_{y_h} - 1)} \qquad (5\text{-}3)$$

$$\varepsilon_{ih} = \frac{\partial y_h}{\partial w_i} \cdot \frac{w_i}{y_h} = -\frac{\alpha_{y_h i} + S_i \cdot S_{y_h}}{\alpha_{y_h y_h} + S_{y_h}(S_{y_h} - 1)} \qquad (5\text{-}4)$$

$$\varepsilon_{hj} = \frac{\partial x_j}{\partial p_h} \cdot \frac{p_h}{x_j} = \left(\frac{\partial x_j}{\partial y_h} \cdot \frac{y_h}{x_j}\right) \cdot \left(\frac{\partial y_h}{\partial p_h} \cdot \frac{p_h}{y_h}\right) = -\frac{\alpha_{j y_h} + S_j \cdot S_{y_h}}{\alpha_{y_h y_h} + S_{y_h}(S_{y_h} - 1)} \cdot \frac{S_{y_h}}{S_j} \qquad (5\text{-}5)$$

Thus, the price elasticities depend on the estimated α-coefficients, as well as the output shares (S_{y_h}) and input shares (S_i) of variable costs. Evaluating these elasticities at the overall mean values of S_i and S_{y_h} provides elasticity estimates in the ranges reported in table 5.3.

The elasticities represent the change in yield per activity unit (e.g. crop yield per hectare) due to a one per cent increase in the considered price. For instance, a one per cent increase in the price of barley increases the yield in spring barley by around 0.26 per cent. For most of the lines of production, the estimated elasticities seem fairly constant across farm and soil types, despite significant variations in the cost structure of these farms. This is in particular the case in the crop sectors. Yield elasticity estimates from the other farm types are reported in appendix E.

Table 5.3. Yield elasticities, crop farms on loamy soil								
	Output price	Energy price	Wage rate	Fertiliser price	Pesticide price	Services price	Rough-age price	Concen-trate feed price
Spring barley	0,255	-0,014	-0,129	-0,045	-0,025	-0,010	-0,001	-0,031
Winter barley	0,260	-0,014	-0,132	-0,044	-0,025	-0,011	-0,001	-0,033
Wheat	0,275	-0,015	-0,139	-0,047	-0,028	-0,010	-0,001	-0,035
Pulses	0,200	-0,011	-0,101	-0,034	-0,025	-0,003	0,000	-0,025
Rape	0,350	-0,019	-0,177	-0,064	-0,032	-0,017	0,000	-0,040
Potatoes	-	-	-	-	-	-	-	-
Sugar beets	0,005	0,001	-0,002	-0,009	-0,002	0,000	0,002	0,006
Dairy cattle	0,001	0,000	-0,001	0,000	0,000	0,000	0,000	0,000
Beef cattle	0,001	0,000	-0,001	0,000	0,000	0,000	0,000	0,000
Pigs	0,001	0,000	0,000	0,000	0,000	0,000	0,000	-0,001
Poultry	0,001	0,000	0,001	0,000	0,000	0,000	0,000	-0,002

There exist various other studies trying to estimate the interrelations between input prices and yield levels, as well as yield-related own-price responses for specific inputs. The majority of such studies address the issues of fertilisers (mainly nitrogen) or pesticides, whereas the yield impacts of other inputs have been studied to a lower extent. Despite methodological differences, some of the elasticities in the present study can be compared with estimates from these other studies. It should be kept in mind that the above elasticity estimates are in part based on information from estimates in Rude (1991). Thus, the estimated cross-price elasticities between fertiliser price and crop yields in the current study are consistent with Rude's findings, but the results also seem to correspond reasonably well with other findings (e.g. Burrell, 1989, Jacobsen et al, 1999, England, 1986)[15].

It is however more interesting to evaluate the remaining elasticity estimated (which have not been based on other estimates, as was the case with fertilisers). Surveys of such estimates have been given by Christensen & Schou (1999) and Hansen (1997). One specific example of a study is Ørum (1999), which is based on experimentally based partial crop yield functions. For example, his model suggests a cross-price elasticity between the price of herbicides and wheat yield per hectare around –0.005.

[15] As nitrogen constitutes a (relatively variable) share of total fertiliser use, the cross-price elasticities at around -0.04 between *total fertiliser price* and crop yields are compared with other studies' estimated cross-price elasticities between *nitrogen price* and crop yields, which lie between –0.04 and -0.02 for most crops.

In some of the above-mentioned nitrogen studies, elasticities representing the impact on yield level due to a crop price change have been estimated at between 0.05 and 0.10. The results in the current study (between 0.2 and 0.3 for most crops) are higher than these estimates. It should however be noted that the nitrogen studies have a partial focus, only allowing one input (nitrogen) to vary due to a crop price change, whereas the present study allows all inputs to vary.

As opposed to the behavioural relations presented in the previous chapter, where output was assumed fixed, output may vary under the current profit maximisation due to variations in yield levels. Thus, it is possible to derive and calculate price elasticities for input demands with a Marshallian interpretation, i.e. allowing output to vary. Because activity levels in the respective lines of production is still assumed fixed, the most reasonable interpretation of these elasticities is a short run Marshallian interpretation.

The own- and cross-price Marshallian elasticities of input demands are given by expressions (5-6) and (5-7), respectively

(5-6) $$\varepsilon_{ii}^{M} = \left(\frac{\alpha_{ii} + S_i \cdot (S_i - 1)}{S_i} \right) + \sum_h \left(- \frac{\alpha_{y_h i} + S_i S_{y_h}}{\alpha_{y_h y_h} + S_{y_h}(S_{y_h} - 1)} \right) \cdot \left(\frac{\alpha_{i y_h} + S_i S_{y_h}}{S_i} \right)$$

(5-7) $$\varepsilon_{ji}^{M} = \left(\frac{\alpha_{ij} + S_i \cdot S_j}{S_i} \right) + \sum_h \left(- \frac{\alpha_{y_h j} + S_j S_{y_h}}{\alpha_{y_h y_h} + S_{y_h}(S_{y_h} - 1)} \right) \cdot \left(\frac{\alpha_{i y_h} + S_i S_{y_h}}{S_i} \right)$$

In both expressions, the first term on the right-hand side represents the output-compensated (Hicksian) effect, whereas the second term represents the yield effect, which comprises the effect of an input price change on the marginal cost and the optimal yield adjustment in light of the changed marginal costs.

Average estimates of the Marshallian input demand elasticities for the eight farm groups – taken as a simple mean of the eight groups elasticities – are given in table 5.4. The elasticities represent the changes in input demands due to changed optimal yield levels caused by changed input prices. Hence, the elasticities represent the second term in the Marshallian elasticity expressions (5-6) and (5-7). Standard deviations represent the variation between these farm groups. Detailed results for each of the farm groups are given in appendix F.

Table 5.4. Short-run Marshallian input demand elasticities – average across farm types

	Energy price	Wage rate	Fertiliser price	Pesticide price	Service price	Roughage price	Conc.feed price
Energy	-0,525	-0,008	0,105	0,005	0,032	0,003	0,009
	(0,448)	(0,021)	(0,150)	(0,052)	(0,005)	(0,089)	(0,035)
Labour	-0,106	-0,208	-0,018	-0,488	0,397	0,403	0,055
	(0,234)	(0,096)	(0,105)	(0,491)	(0,060)	(0,069)	(0,213)
Fertiliser	0,290	0,001	-0,471	0,536	0,081	0,823	-0,043
	(0,307)	(0,025)	(0,239)	(0,292)	(0,040)	(1,148)	(0,086)
Pesticides	0,041	-0,036	0,197	-0,851	0,009	0,312	0,080
	(0,079)	(0,033)	(0,105)	(0,126)	(0,071)	(0,504)	(0,116)
Services	0,041	0,042	0,041	-0,021	-0,400	-0,823	-0,024
	(0,016)	(0,016)	(0,016)	(0,164)	(0,522)	(2,779)	(0,115)
Roughage	-0,010	0,008	0,055	0,160	-0,032	-1,064	-0,988
	(0,050)	(0,012)	(0,088)	(0,284)	(0,135)	(0,687)	(0,032)
Conc.feeds	0,101	0,233	-0,097	-0,125	0,302	0,416	0,257
	(0,274)	(0,164)	(0,323)	(0,725)	(0,388)	(1,297)	(0,410)

Note: standard deviations in parantheses

As compared with the Hicksian elasticity estimates presented in the previous chapter, the Marshallian input demand elasticities are smaller, because an input price increase will lead to lower yield levels and hence lower demands for the respective inputs. Comparing the elasticities in table 5.4 with the Hicksian ones in table 4.3 also reveals that the yield effects constitute a minor share of the total short-run Marshallian demand effects – the dominating component of most input demand elasticities stem from input substitution, including substitution between commercial fertilisers and utilisation of animal manure (represented by e.g. higher labour efforts), and between chemical and mechanical pest control (also represented by e.g. labour).

6. Equations for profit maximising land use, animal stocks and capital input

In this chapter, the formulation and estimation of behavioural equations describing the use of land and capital (including livestock) on Danish farms are documented. Profit maximisation is a basic behavioural assumption in the description of these variables. This implies that if production of a specific crop becomes more profitable (relative to other crops), farmers are assumed to allocate a larger share of their agricultural area to this specific crop at the cost of other crops. Furthermore, the assumption implies that if e.g. pig production becomes relatively more profitable, a larger share of the farmer's activities is devoted to pig production etc.

The second basic assumption underlying the model for land use and capital (including livestock) is that adjustments in these variables take time, due to e.g. crop rotation restrictions, production lags in animal production, "conservative" behaviour, etc. Therefore, a dynamic description of the adjustment process is necessary.

The model documented in this chapter describes the composition of agricultural activities on 8 different farm types (cf. previous chapters) in terms of nested sets of elasticities of transformation between these activities in the long run, and in different intermediate time horizons. The chapter includes theoretical derivation of behavioural equations (section 6.1), formulation of empirical estimation equations (section 6.2), estimation procedure and results (sections 6.3 and 6.4) and evaluation of the model (section 6.5).

6.1. Theoretical framework

The following theoretical considerations represent an expansion of the framework underlying chapters 4 and 5. As in chapter 5, a basic assumption underlying the model is that farmers exhibit profit maximising behaviour. In general, farm profit can be expressed as

(6-1) $$\max \Pi = \sum_{h=1}^{H} p_h \cdot Y_h - \sum_{i=1}^{I} w_i X_i$$

where Y_h is the quantity of output h, X_i is the quantity of input i, p_h is the price of output h and w_i is the price of input i. If the total area available to the farm cannot be increased, expansion in one land-using sub-sector must be offset by contractions in other land-using sub-sectors on a specific farm. Thus, this restriction introduces a trade-off between potential economic gains by increased activity and output in one sub-sector and losses due to reduced activity in other sub-sectors.

The profit function (6-1) is maximised subject to the technological possibilities, represented by the transformation function

(6-2) $$F(Y, X, Z) = 0$$

where Y is a vector of variable outputs, X is a vector of input quantities (except land) and Z represents the total area available. The transformation function should reflect a production possibilities set, which satisfies standard properties of multi-output technologies, including non-emptiness, convexity and free disposability of Y, X and Z (see Chambers, 1988, p. 252). From the transformation function, we can derive the marginal rate of product transformation (MRPT), i.e. the rate at which one output displaces another in a multiproduct tehnology with a fixed input bundle (Chambers, 1988, p. 255), between any two outputs or inputs by differential calculus. Hence, the MRPT between outputs h and g can be derived from (6-2) as

(6-3a) $$dF = 0 \Rightarrow \frac{dY_h}{dY_g} = -\frac{\partial F / \partial Y_g}{\partial F / \partial Y_h}$$

and between an input and an output

(6-3b) $$dF = 0 \Rightarrow \frac{dY_h}{dX_i} = -\frac{\partial F / \partial X_i}{\partial F / \partial Y_h}$$

Decomposing the input and output quantities in an activity component and an intensity component in each line of production, the transformation function can be restated as

(6-4) $$F(z, y, x, Z) = 0$$

where z represents the vector of activity levels, and y and x represent the matrices of outputs and inputs from each of the activities. Most outputs are only represented in one line of production (e.g. a farm's production of pork, milk etc.) whereas many inputs are represented in several lines of production (e.g. use of fertilisers, Energy, labour). The point in this decomposition is to enable distinction between product transformation in terms of activity levels (e.g. land allocation issues) and other input-output transformation in terms of production intensity (i.e. movements along traditional one-output production frontiers in the respective lines of production). The latter dimension can be seen by considering the use of more fertiliser to increase wheat yield per hectare as an increase in the wheat yield output at the cost of an increase in the fertiliser input (or a decrease in net fertiliser output).

Having reformulated the transformation function, two (partial) types of MRPT can be derived - an intensity-oriented MRPT concerning production intensity and input composition within individual lines of prodution, and an activity-oriented MRPT concerning the composition of production activities. Other types of partial MRPT's might be defined as well (e.g. between yield levels in different lines of production with everything else being kept contant), but their economic interpretations are less obvious than the two measures considered in the following.

The intensity-oriented MRPT addresses the composition of yield level and input application, as well as the composition of inputs in the respective lines of production. By taking total derivatives of (6-4), an expression for MRPT can be derived as

(6-5a) $$\frac{\partial y_h}{\partial x_{jh}} = -\frac{\partial F / \partial x_{jh}}{\partial F / \partial y_h}$$

(6-5b) $$\frac{\partial x_{jh}}{\partial x_{jg}} = -\frac{\partial F / \partial x_{jg}}{\partial F / \partial x_{jh}}$$

Essentially, expression (6-5) is just another way of expressing the marginal product of a variable input or the marginal rate of technical substitution between two variable inputs in standard one-output production theory. These issues are treated thoroughly in the previous two chapters and will not be dealt further with in this chapter.

On the other hand, the activity-oriented MRPT addresses the determination of activity levels in the respective lines of production, including land allocation. An expression for the activity-oriented MRPT between activity in sub-sectors h and g can be derived from the transformation function as

(6-6) $$\frac{dz_h}{dz_g} = -\frac{\partial F / \partial z_g}{\partial F / \partial z_h}$$

In profit maximising equilibrium, the MRPT equals the ratio between economic returns r in sub-sectors h and g, i.e.

(6-7) $$\frac{dz_h}{dz_g} = -\frac{r_g}{r_h}$$

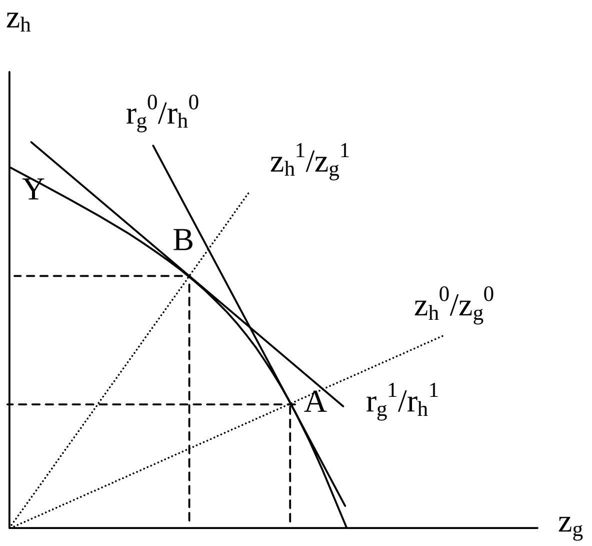
Expression (6-7) states that if activity composition is in equilbrium, no economic gains can be earned by changing the composition of agricultural activities, because the extra opportunity cost of increasing the activity in one sector by one unit offsets the potential extra profit to be earned by that increase. The economic returns in different sub-sectors depend on the prices of agricultural outputs and inputs. Hence, if a change in e.g. the price of fertiliser is more favourable to sub-sector h than to sub-sector g, the ratio of economic returns in (6-7) – and hence the MRPT – will increase. As the transformation function is assumed to be well-behaved, this implies that z_h increases relative to z_g. A measure of the sensitivity of activity composition with respect to changes in relative profitabilities is the elasticity of transformation:

(6-8) $$\sigma_{hg} = \frac{\partial\left(\frac{z_h}{z_g}\right)}{\partial\left(\frac{r_g}{r_h}\right)} \cdot \frac{\frac{r_g}{r_h}}{\frac{z_h}{z_g}}$$

An interpretation of the elasticity of transformation is given in figure 6.1.

The Y-curve represents the transformation function (6-4), which reflects the set of efficient combinations of activities h and g. The marginal rate of activity transformation is given by the slope of the Y-curve. If the farm maximises profits, the marginal rate of transformation should equal the ratio between the economic returns to the two activities (equal to the slope of the tangent - r_g^0/r_h^0). Given the initial rates of return r_h^0 and r_g^0, respectively, the profit maximising combination is represented by the point A in the figure. The slope of the secant (z_h^0/z_g^0) represents the composition of the two activities. If the relative rates of return change (for instance, r_h increases relative to r_g), the optimal combination changes, represented by the point B in the figure. The elasticity of transformation in expression (6-8) can be determined as the percentage change in the secant slope, divided by the percentage change in the tangent slope.

Figure 6.1. Graphical interpretation of elasticities of transformation



As is well-known from the literature on elasticities of substitution (e.g. Chambers, 1988, Varian, 1984), such elasticities may have different interpretations in a multiple-activity setting, depending on the assumptions concerning variables outside the pair represented by the elasticity expression. As is discussed in relation to the empirical model below, this does not pose an important problem in the current context, because we impose a pairwise nest structure on most of the activities.

If the transformation function satisfies the above-mentioned standard properties, the optimisation problem outlined above can be represented by a dual profit function.

(6-9) $$\Pi = \Pi(p, w, Z) = \Pi^1(r(p, w, Z), Z) + \Pi^2(p, w, Z)$$

The first version of the dual profit function in expression (6-9) is the “standard” formulation: variable profit depends on the vector of input and output prices, as well as the endowments of quasi-fixed factors. In the second version in (6-9), the dual profit function is decomposed into two components: a component (Π^1) depending on the vector of economic returns to the respective lines of production, which again depends on the vector of prices, and a (residual) component (Π^2), representing the part of the profit, which is not captured by the first component. The decomposition of the profit function in (6-9) corresponds to the decomposition of the transformation function (6-4). It divides the profit function into a ‘structured’ and a ‘residual’ component. In the structured part, price and area information is aggregated into a vector of economic returns, and the residual component represents the ‘aggregation error’ in this relation. The smaller the residual term, the more valid is the aggregation scheme.

Using standard derivation principles[16], we can derive the profit maximising activity levels from the profit function (6-9)

(6-10) $$z_h = \frac{\partial \Pi}{\partial r_h} = \frac{\partial \Pi^1}{\partial r_h}$$

Basically, the analysis in the chapter aims at estimating equations corresponding to (6-10) for Danish farms.

6.2. Empirical model

Based on the theoretical framework outlined in the previous section, an empirical model can be formulated. This involves the specification of functional form and dynamics, as well as addressing the question of data availability for econometric estimation.

In the following, we assume that the sub-sector net profit rate functions can be decomposed as

(6-11) $$r_h(p_h, w_1,..., w_I, z_1,..., z_H) = r_h^w(p_h, w_1,..., w_I) \cdot r_h^z(z_1,..., z_H)$$

That is, a component depending only on output and input prices and another component depending only on activity levels. Hence, we assume separability between prices and activity levels in the profit rate functions. This assumption implies that the composition of inputs and outputs in sub-sector h is independent of the scale of activity in the different sub-sectors. The second component of the net profit rate (r_h^z) is assumed to have a unit mean value, but the component may differ from unity to the extent that the activity levels on the farm differ from the mean activity levels on the considered farm type.

---

16 The principles are analogous to Hotelling’s lemma for profit maximisation or the Samuelson-McFadden lemma (Chambers, 1988, p. 264) for revenue maximisation.

In the empirical specification, we assume that the profit maximisation problem outlined in section 6.1 can be represented by a translog profit function:

$$
\begin{aligned}
(6\text{-}12)\quad & \ln\Pi(p_1,\ldots,p_H,w_1,\ldots,w_I,Z,t)=\ln(\textstyle\sum_{h=1}^{H} z_h \cdot r_h)= \\
& \alpha_0+\textstyle\sum_{h=1}^{H}\alpha_h \cdot \ln(r_h^w \cdot r_h^z)+½\cdot\sum_{h=1}^{H}\sum_{g=1}^{H}\alpha_{hg}\cdot\ln(r_h^w \cdot r_h^z)\cdot\ln(r_g^w \cdot r_g^z) \\
& \alpha_Z \ln Z+½\alpha_{ZZ}\cdot(\ln Z)^2+\alpha_t t+½\alpha_{tt}t^2 \\
& +\textstyle\sum_{h=1}^{H}\alpha_{hZ}\cdot\ln(r_h^w \cdot r_h^z)\cdot\ln Z+\sum_{h=1}^{H}\alpha_{ht}\cdot\ln(r_h^w \cdot r_h^z)\cdot t
\end{aligned}
$$

Hence, the price-dependent component of the sub-sector net profit rates are considered as price variables in the profit maximisation problem. In addition to these variables, the total area available Z and a linear trend variable t are included in the specification, in order to capture differences in farm size and the impacts of technological change, respectively.

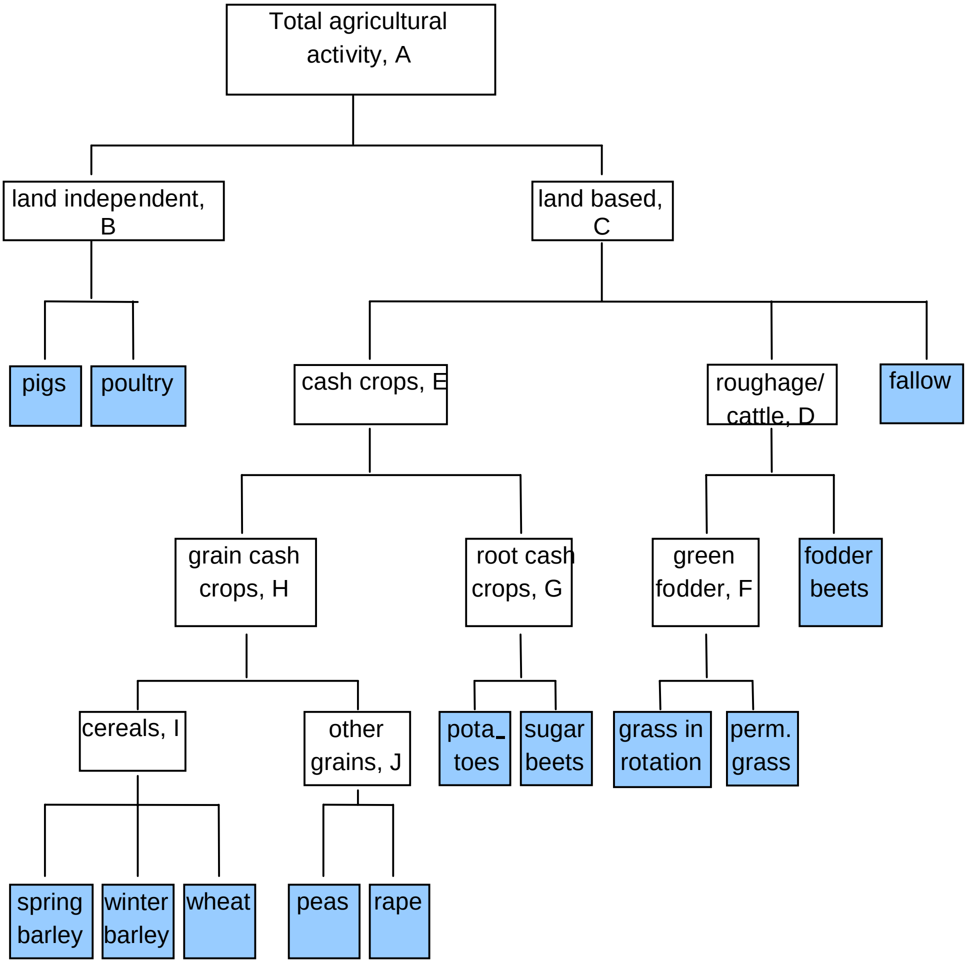
Applying Hotelling's lemma to the profit function, the profit maximising activity levels in the respective sub-sectors can be derived, in terms of profit shares, as

$$
(6\text{-}13)\quad W_h=\frac{z_h r_h}{\sum_{g=1}^{H} z_g r_g^w}=\frac{\partial\ln\Pi}{\partial\ln r_h^w}=\left[\alpha_h+\sum_{g=1}^{H}\alpha_{hg}\ln r_g^z\right]+\sum_{g=1}^{H}\alpha_{hg}\ln r_g^w+\alpha_{hZ}\ln Z+\alpha_{ht}t
$$

Thus, the respective sub-sectors' shares of total profit on the farm can be represented by linear functions of the logarithmic net profit rates, the farm's logarithmic total area and the linear trend variable. Note that, the area-dependent component of sub-sector profit rates is included in the constant term.

In order to simplify the model and reduce the number of behavioural parameters to be estimated below, we impose a separability (nesting) structure on the model's allocation mechanisms. Imposition of the separability structure implies that the activity levels model is decomposed into 10 sub-models. Each of the sub-models nests two or three underlying sub-sectors or sub-sector aggregates into one composite "sector". The imposed separability structure is shown in figure 6.2.

Figure 6.2. Imposed separability structure[17]



[17] Numbers in the sub-sector aggregate boxes refer to sub-model, cf. below.

For example, the composition of peas and rape into the aggregate group of pulses/rape depends on the relative profitabilities between these two crops, whereas the composition is assumed to be independent of the profitability in e.g. wheat, potatoes or cattle. The constructed separability structure may be justified by the time horizon considered in the estimations. Hence, the transformation between roughage (and cattle) and cash crops has a relatively structural nature including more heavy decisions than those underlying the switch between different cereals or between cereals and rape or pulses. Production of potatoes and sugar beets is to a large extent regulated by contracts, thus switches between these crops and e.g. cereals may be expected to be relatively rigid.

As mentioned, the imposed separability structure allows us to divide the model into a number of more simple models, each describing the composition of two or three sub-sectors (or sub-sector aggregates). For example, one model determines the composition of peas and rape as a function of the profitabilities in these two sectors alone, as well as the total area and the trend variable. Another model describes the composition of land based and non-land based agricultural activities as a function of the aggregate profitabilities on land based and non-land based activities, respectively, along with total area and trend variable. At the aggregated levels, the composition of activity aggregates depend on aggregate profitability indexes (where aggregation of sub-sector profitabilities has been carried out in terms of Törnquist indexes).

Separability between landbased and “non-landbased” (pigs and poultry) activities implies that the number of pigs or poultry units per hectare has no impact on the crop composition. It should be noted that in the last 5 years of the estimation period (and afterwards) livestock production has been subject to a livestock density requirement imposing an upper limit to the number of livestock units per hectare, which is binding for some farms. This has not been explicitly accounted for in the estimations. Hence, for pig farms with high livestock density, this may imply that the model’s flexibilty in pig activity adjustment is overestimated, especially in the upward direction.

Within a given nest (e.g. the composition of peas and rape within the pulses/rape aggregate), the change in composition due to a change in the relative profitabilities can be expressed in terms of elasticities of transformation, such as

$$\sigma_{hg} = \frac{\partial(z_h / z_g)}{\partial(r_g / r_h)} \cdot \frac{(r_g / r_h)}{(z_h / z_g)} = \frac{\alpha_{hg} + W_h W_g}{W_h W_g} \qquad (6\text{-}14)$$

where W_h and W_g represent peas' and rape's shares of total net profit in the pulses/rape sector, i.e. $W_g = (1-W_h)$.

The elasticity expression in (6-14) represents the changes in the composition of peas and rape areas due to changes in the relative profitabilities between these sub-sectors. In addition, changed profitability in one or both of these sectors affects the aggregate profitability in the pulses/rape sector and hence the composition of the pulses/rape- and the cereals-aggregates, and so forth.

The cattle sector is integrated in roughage production, in that the density of cattle per hectare of roughage is assumed to be fixed. Thus, the economic profits from cattle production is directed to the respective roughage areas in proportion to the different roughage sub-sectors' contribution to the total number of feed units on the farm.

Having imposed the nest structure outlined in figure 6.1, the model can be decomposed into 10 nested sub-models, which are summarised in box 6.1. These models can be estimated separately, provided the imposed nest structure is reasonable. Sub-models describing transformation between two lines of production or aggregates can be represented by one estimation equation, whereas sub-models describing the transformation between three crops or crop aggregates can be represented by two estimation equations, because one estimation equation can be dropped in each case.

Box 6.1.	**10 nested sub-models, transformation between …**
Model A:	land-based production (including cattle, which is linked to roughage production) and land-independent production (pigs and poultry)
Model B:	pigs and poultry
Model C:	roughage (including cattle), fallow and cash crops
Model D:	green fodder and fodder beets
Model E:	grain cash crops and root cash crops
Model F:	grass/greenfodder in crop rotation and permanent grass
Model G:	potatoes and sugar beets
Model H:	cereals and other grain cash crops (pulses, rape)
Model I:	spring barley, winter barley and wheat
Model J:	peas and rape

Dynamic specification

As mentioned in the introduction to this chapter, there are several bindings on the activity levels in different agricultural sub-sectors in the short run. For example, it takes more than two years to bring up a dairy cow. Expansion in the livestock sectors may also be hampered by adjustment costs related to the investment in animals, buildings or equipment necessary for the expansion.

Land allocation can be affected by crop rotation concerns – it takes time to change crop rotation schemes markedly. Farmers' decisions concerning crop rotation and livestock adjustments may also be the result of skills/preferences, "wait and see" attitudes (e.g. due to risk aversion), financial constraints etc. Furthermore, institutional settings have also hampered swift changes in agricultural production (e.g. relatively limited possibilities for transferring milk quota). Thus, there are several reasons for assuming that activity levels in the agricultural sub-sectors on Danish farms represent adjustment processes rather than long-run equlibria, and hence that an empirical model for describing these aspects should be dynamic.

For econometric estimation of dynamic (intertemporal) relationships, data series must be stationary, i.e. exhibit a constant mean, constant variance and constant intertemporal correlation (see e.g. Harvey, 1981, p. 25). Although most economic data series are non-stationary in levels (e.g. due to trend, inflationary components etc.), their first (or higher) order differences (i.e. the change in a variable from time t to t+1) may be stationary. The concepts of integrated[18] and cointegrated[19] economic variables are useful for econometric analysis of dynamic relations, because they enable combined analysis of long-run- and short-run relationships between data series. This feature can be seen by the "error correction" specification, which also forms the basis for the analysis below[20].

In the current work, we formulate farmers' determination of sub-sector activity levels due to an "error correction" specification (see e.g. Engle & Granger, 1987). The error correction formulation of the profit share equation (6-13) is

(6-15)
$$\begin{aligned}\Delta W_{h,t} &= \gamma_{ht} + \textstyle\sum_{g=1}^{H} \gamma_{hg} \cdot \Delta \ln r_{g,t}^{w} + \gamma_{hZ} \cdot \Delta \ln Z_t \\ &- \eta_h \cdot \left[W_{h,t-1} - \textstyle\sum_{g=1}^{H} \alpha_{hg} \cdot \ln r_{g,t-1}^{w} - \alpha_{hZ} \cdot \ln Z_{t-1} - \alpha_{ht} \cdot (t-1) \right]\end{aligned}$$

[18] If first order differences of a data series are stationary, the data series is said to be I(1) - integrated of order 1. Similarly for higher orders of integration.

[19] A number of data series are said to be cointegrated of order d,b - CI(d,b) - if all series are integrated at orders no higher than d, and there exists a linear combination of the data series, which is integrated of an order (d-b), b > 0.

[20] Another, and less restrictive, formulation is the Vector AutoRegressive (VAR) specification (see. e.g. Lind, 1998)

Hence, the error correction mechanism consists of two main components:

I short run responses to changes in the explanatory variables, represented by the Δ-terms on the right-hand side

II adjustment towards long-run equilibrium in terms of reducing the "error" (deviation from long-run equilibrium) from the preceding year, represented by the bracketed term. The coefficient η_h represents the speed of adjustment in this process.

Hence, the error correction specification enables explicitly combining two types of dynamic processes in one model: short-run responses to changes in economic conditions and underlying adjustments towards long-run equilibrium (where long-run equilibrium depends on economic conditions as well and thus the target for the long-run adjustment may be variable).

Estimation of the error correction specification is possible, if the involved terms are stationary. This implies that the differences should be stationary (the underlying series are I(1)), and that the bracketed term should be stationary as well (the series within brackets are CI(1,1)). An economic interpretation of cointegration is that there exists a stable long-run relationship between a set of data series, although the individual data series are non-stationary. The vector of coefficients in a cointegrating linear combination of the non-stationary data series is normally termed the 'cointegrating vector'[21].

6.3. Data

The data material used for econometric estimation of the empirical model comprises farm accounts data and data concerning average economic returns in different agricultural lines of production[22]. Whereas the farm account data include information on land use, livestock herds, yields, costs, incomes etc. at the farm level for a large number of individual farms, which can be organised as a panel data set (cf. previous chapters), the latter data describe average yields and various costs per hectare or animal in different agricultural activities, but are in general not known at the individual level.

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[21] see e.g. Engle & Granger, 1987, for more on integrated and cointegrated variables.

[22] Danish Institute of Agricultural and Fisheries Economics, Series B.

We combine these two data sources in order to obtain a panel dataset suitable for econometric estimation. When including the sub-sector data in the dataset, we assume that the *movements* in relative economic returns between different agricultural sub-sectors on individual farms are equal to those at an aggregate level, whereas the levels of sub-sector economic returns may vary among farms.

As has been mentioned in earlier chapters, the farm accounts dataset can be characterised as an unbalanced panel, because individual farms are represented in different numbers of subsequent years. Due to the dynamic specifications used in the current part of the model, the farms used in the econometric estimations must be represented several periods in the data material. Setting this number of periods involves a trade-off between the size of the dataset and the meaningfulness of econometric estimation in the current dynamic setting. In the current work, farms which are represented less than 6 subsequent years[23] in the sample have been omitted for the dataset used for the current estimation. Furthermore, not all of the 10 sub-models outlined above are relevant on all farms. For instance, if a farm has not produced potatoes in the data period, it does not make sense to attempt econometric estimation of behavioural parameters concerning the use of land for potato production. Consequently, such data are also deleted from the dataset when estimating the specific sub-models.

Decomposing the resulting data set into the 8 farm groups considered in the previous chapters, yields the numbers of observations shown in table 6.1. Due to the concern that the relevant product transformations must exist on the data farms, the number of observations in a given farm group depends on the sub-model to be estimated.

To give an impression of the production structure in each of the nests on the 8 farm types, the partial shares of profits in the sub-models on the 8 farm types are shown in table 6.2.

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[23] It should be noted that compared with current literature on error correction models, cointegration analysis etc., 6 years is a relatively short time period. Sensitivity analyses have been conducted with respect to this number, and results are not changed drastically when changing the number to 5 or 7 years.

Table 6.1. Numbers of observations in various sub-models

	Crop, loam	Crop, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Parttime, loam	Parttime, sand
A	44	20	37	305	48	107	-	-
B	22	-	37	177	-	-	-	-
C	13	11	57	595	-	9	-	17
D	94	17	35	652	40	50	23	51
E	114	27	17	61	-	-	-	-
F	111	31	23	284	51	69	19	59
G	-	-	-	-	-	-	-	-
H	39	21		38	21	66	-	26
I	76	-	19	40	28	26	-	-
J	13	-	-	32	-	19	-	-

Note: "-" implies that there were too few observations for econometric estimation.

Table 6.2. Partial profit shares in various sub-models

	Crop, loam	Crop, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Parttime, loam	Parttime, sand
A: Land based	0.712	0.734	0.870	0.894	0.416	0.299	-	-
B: Pigs	0.044	-	0.707	0.879	-	-	-	-
C: Cattle	0.040	0.090	0.689	0.751	-	0.183	-	0.405
Fallow	0.000	0.000	0.000	0.000		0.000		0.000
D: Greenfodder	0.600	0.612	0.564	0.630	0.601	0.620	0.617	0.592
E: Grain	0.637	0.645	0.447	0.887	-	-	-	-
F: Rot. greenfod.	0.735	0.650	0.749	0.799	0.717	0.670	0.776	0.714
G: Potatoes	-	-	-	-	-	-	-	-
H: Cereals	0.849	0.743	-	0.751	0.753	0.706	-	0.701
I: Spring barley	0.406	-	0.656	0.632	0.454	0.618	-	-
Winter barley	0.010		0.000	0.030	0.000	0.030		
J: Peas	0.477	-	-	0.576	-	0.442	-	-

Note: "-" implies that there were too few observations for econometric estimation

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For example, crop farms on loamy soil earn 71.2 per cent of total profits from land-based agricultural activities (crop and cattle production) and the remaining 28.8 per cent from pigs and poultry. Of the 71.2 per cent from landbased activities, 4 per cent of profits from land-based activities are due to cattle production.

6.4. Estimation procedure

The validity of the error correction specification requires the existence of a long-run relationship or co-integration between the variables concerned. Furthermore, a condition for co-integration is that the variables concerned are integrated of the same order.

These requirements lead to the following 5 steps of the estimation and testing procedure:

1. identify order of integration in individual data series
2. identify and estimate possible cointegrating relations
3. calculate deviations from long-run equilibrium
4. estimate error correction equation
5. evaluate the model

In the following, the use of these steps in the current study and some results will be discussed in turn.

Ad 1. Identify order of integration in data series

For pure time series data, various tests for order of integration has been developed, including the simple and augmented Dickey-Fuller tests and the Phillips-Perron test (see e.g. Hallam et al., 1993, for a brief introduction to these tests). The main unit root tests developed for panel data draw on the augmented Dickey-Fuller approach, which in general is based on regressions of the type

(6-16) $$\Delta x_t = \delta x_{t-1} + \sum_{i=1}^{p} b_i \Delta x_{t-p} + \varepsilon_t$$

where an insignificant[24] δ-parameter is an indication of a unit root in the data series. One approach to panel data, put forward by Levin & Lin (1993), performs an augmented Dickey-Fuller test on panel data, which are transformed in order to ensure independence between data series for different individuals as well as adjustments for individual variance differences. The Levin-Lin procedure tests only the existence of a common unit root, whereas individuals may differ in other respects. The authors state that the test only poses moderate requirements to the minimum length of the time dimension (25 periods) and number of individuals (10 individuals).

A second approach, which to some extent builds on the Levin-Lin approach is a Lagrange Multiplier test put forward by Im, Pesaran & Shin (1996). The test procedure also takes departure in the Dickey-Fuller equation, but is more flexible in that it allows data series to have unit roots for some individuals whereas series for other indi-

[24] A crucial point in relation to the Dickey-Fuller test is to determine critical values for the t-ratio corresponding to the δ-parameter.

viduals are stationary. Hence, the null is that the data series have unit roots for all individuals, and the alternative is that at least one individual has a stationary series. The authors point out that the small-sample properties of this test procedure are more satisfactory than those of the Levin-Lin procedure, indeed when data series are not serially correlated. Therefore, the test proposed by Im, Pesaran and Shin (IPS) has been applied. Results from the unit root tests are given in table 6.3.

Table 6.3. Unit root tests for variables, crop farms on loamy soil

Variable	IPS-test	Conclusion	Variable	IPS-test	Conclusion
Spring barley share	-2,44		rel spring barley profit	-6,16	
Winter barley share	-1,56	I(1)	rel. winterbarley profit	-0,94	I(1)
Pulses share	-1,03	I(1)	rel. pulses profit	0,89	I(1)
Potatoes share	-0,71	I(1)	rel. potatoes profit	-0,08	I(1)
Rot.grass share	1,07	I(1)	rel. rot.grass profit	0,26	I(1)
Pig share	0,34	I(1)	rel. pig profit	-1,40	I(1)
Grass share	-0,81	I(1)	rel. grass profit	0,72	I(1)
Cereals share	-1,10	I(1)	rel. cereals profit	5,85	
Reform crop share	-1,18	I(1)	rel. reform profit	8,00	
Roughage share	0,22	I(1)	rel. roughag profit	4,12	
Veg. share	0,40	I(1)	rel. landbased profit	10,31	

IPS: Im, Pesaran & Shin's test statistic for integration of order 1

With the current data material, the tests are however relatively weak, due to the relative short periods (6-8 years) for which the individual farms are represented. In general, the tests suggest the existence of unit roots in the series for rates of return as well as in the series for different sub-sectors' shares of total profit shares.

Ad 2. Identify and estimate possible cointegrating relations

Having identified the order of integregation in the individual data series, next step is to identify possible cointegrating relations between the variables. In general, two basic approached have been suggested for cointegration tests and estimation of cointegration relationships:

- a regression based methodology, launched by Engle & Granger (1987)
- a maximum likelihood methodology suggested by Johansen (1988)

Basically, the former approach relies on a 'spurious' regression of the variables (integrated of the same order) on each other, and if the series of residuals from this regression is integrated at an order lower than the variables, the variables are co-integrated, and the estimated set of regression coefficients is the cointegrating vector. One limitation to this approach is that distinction between different cointegrating relationships is difficult. Engle & Granger (1987) put forward a number of test statistics, which can be calculated on the basis of the 'cointegrating' regression. On the basis of their framework, Kao (1999) develops tests for cointegration in panel data based on residuals from a 'spurious' regression, using different modifications and normalisations to the Dickey-Fuller approach, cf. above.

The 'Johansen'-approach aims at determining the rank of the cointegrating matrix (and hence the number of independent cointegrating vectors) by determining the number of non-zero eigenvalues of the cointegrating matrix using a maximum likelihood estimation procedure. Hence, the Johansen approach is suitable, when more than one cointegrating vector is suspected. Larsson et al. (1998) develop a test for cointegration in heterogenous panel data based on the Johansen methodology. As the model specifications in the current study are relatively simple, we assume no more than one cointegrating relation in each of the sub-models. Thus, estimation and testing for cointegration has been carried out by means of spurious regressions and the derived Dickey-Fuller-based tests suggested by Kao (1999).

The general form of the potential cointegration equation is given by the expression

$$(6\text{-}17)\quad W_{h,t-1}^{f} = \alpha_h^f + \sum_{g=1}^{H} \alpha_{hg} \cdot \ln r_{g,t-1}^{w} + \alpha_{hZ} \cdot \ln Z_{t-1}^{f} + \sum_{k=1}^{K} \alpha_{hq_k} \cdot \ln q_{k,t-1}^{f} + \alpha_{ht} \cdot t + e_{t-1}^{f}$$

where q represents the same additional explanatory variables as in chapters 4 and 5. t is a linear trend variable. Estimation results for 8 of the 10 long-run models are shown in table 6.4.

The residuals from the cointegration regressions reported in table 6.4 form the basis for testing for cointegration, due to the Dickey-Fuller regression-based test approaches proposed by Kao (1999). Kao derives a number of test statistics, which are all asymptotically N(0,1) under the null hypothesis of I(1)-residuals.

Hence, a test statistic inside the interval between the 5 per cent fractile and the 95 per cent fractiles [-1.645 : 1.645] leads to failure in rejecting the null hypothesis, whereas test statistics outside this interval leads to rejection of I(1)-residuals, and hence the conclusion that the variables in the expression are cointegrated – if none of the variables in the expression are integrated of orders higher than one. Two types of test statistics are considered:

I. statistics related directly to the coefficient of the lagged variable (δ) in the Dickey-Fuller regression (DF_{δ}^{*} and DF_{δ}), and
II. statistics related to the t-value of the estimated δ -coefficient (DF_{t}^{*}).

Table 6.4. Estimated coefficients in selected long-run models, crop farms on loamy soil

	Model B $S_{pig}/(S_{pig}+S_{plt})$	Model C $S_{rgh}/(S_{rgh}+S_{csh})$	Model D $S_{grf}/(S_{grf}+S_{fbt})$	Model E $S_{grn}/(S_{grn}+S_{root})$	Model F $S_{rgs}/(S_{rgs}+S_{pgs})$	Model H $S_{crl}/(S_{crl}+S_{prp})$	Model I $S_{brl}/(S_{brl}+S_{wht})$	Model J $S_{pea}/(S_{pea}+S_{rap})$
$r_{pig\text{-}poult.}$	0.2337 (0.1321)	-	-	-	-	-	-	-
$r_{rough.\text{-}cash}$	-	0.0978 (0.0140)	-	-	-	-	-	-
$r_{green\text{-}fbeet}$	-	-	2.4319 (0.0459)	-	-	-	-	-
$r_{grains\text{-}root}$	-	-	-	0.2361 (0.0350)	-	-	-	-
$r_{rot.\text{-}perm.}$	-	-	-	-	6.5052 (0.6133)	-	-	-
$r_{cer.\text{-}puls/rap}$	-	-	-	-	-	0.4545 (0.0964)	-	-
$r_{sp.barl\text{-}wheat}$	-	-	-	-	-	-	0.3325 (0.1124)	-
$r_{peas\text{-}rape}$	-	-	-	-	-	-	-	1.2740 (0.3108)
ln Z	-	-0.4446 (0.1562)	-	-	0.0660 (0.0288)	-	-	-0.1954 (0.0993)
t	-	-	-	-	0.0022 (0.0005)	-	-	-
ec.size	0.7976 (0.1893)	-	-	0.0707 (0.0136)	-	-0.1327 (0.0289)	-0.1104 (0.0423)	-
crop share	-	-	-	-0.2483 (0.1312)	-0.4404 (0.2089)	-0.8645 (0.3190)	-0.7669 (0.2302)	-
Cattle share	-	-	-	-0.6056 (0.2286)	-0.7735 (0.3473)	-	-	-
D92	-	0.4587 (0.1890)	0.0261 (0.0046)	-	-0.1581 (0.0480)	0.1097 (0.0576)	-	-
eff.prox	-	-	-	-	-	-	-0.0175 (0.0041)	-

Note: Standard deviations in parentheses

Results of the tests for cointegration for crop farms on loamy soil are reported in table 6.5.

The test statistics in table 6.5. (and similarly for other farm types) do not in general provide a clear recognition whether the residuals from the cointegrating regressions are either I(1) or I(0), and hence whether the variables in the regression equations are cointegrated or not. It should be noted that due to the relative short represenation of each farm (normally 6-8 years per farm), the power of these tests is limited.

Table 6.5. Results of regression based tests for cointegration, crop farms on loamy soil

	DF_δ^*	DF_δ	DF_t^*	H_0: I(1)
Model A	0.500	-1.441	-1.497	
Model B	1.873	0.871	2.489	(reject)
Model C, eq. 1	1.105	0.287	0.648	
eq. 2	-2.159	0.268	-0.930	
Model D	1.136	-3.097	-2.674	reject
Model E	1.477	-2.302	-1.418	(reject)
Model F	3.850	1.864	4.308	reject
Model G	-	-	-	
Model H	2.122	-0.384	-0.400	(reject)
Model I, eq. 1	1.679	-1.330	-2.138	reject
eq. 2	0.671	-0.978	1.498	
Model J	1.018	0.645	0.870	

Ad 3. Calculate deviations from long-run equilibrium

The estimated cointegrating equations between model variables represent the long-run relationship between these variables. Engle & Granger (1987) demonstrate that under proper conditions, the OLS-estimate of the cointegrating vector (the 'cointegrating regression') is 'super-consistent'. Hence, residuals from these cointegrating relations can be considered as deviations from long-run equilibrium – representing the bracketed term in expression (6-15).

The rationale behind the cointegrating regression is that when considering sufficiently long time periods, deviations from long-run equilibrium can be considered to fulfil standard regression conditions. A problem with interpreting these residuals from a cointegrating regression as deviations from long-run equilibrium is the relative short representation of individual farms in the panel. If the representation is 'too' short, the results of the cointegrating regression will be biased in that they will tend to underestimate the extent of disequilibrium, if the cointegrating regression is performed using panel data estimation methodology (e.g. a fixed effects-model). On the other hand, an ordinary estimation technique (not taking into account the panel characteristics of data), may imply an overestimated disequibrium, because the variation between individuals will be included in the estimated extent of disequilibrium. As discussed by Quah (1994) and Levin & Lin (1993), panel data sets with many individuals can compensate for these problems, because positive bias for some individuals are outweighed by negative bias for other individuals.

In the current study, we use panel data methods, using a within-groups estimator. Thus, we run the risk of underestimating the extent of disequilibrium, although some of the adjustment processes (mainly land allocation) are expected to be relatively rapid, which together with the panel size could be expected to reduce this risk of bias.

Ad 4. Estimate error correction equation

Based on the estimated deviations from long-run equilibrium (residuals in the cointegrating regression), an error correction equation, cf. expression (6-15), can be estimated using a regression technique (cf. Engle & Granger, 1987, and various other studies). The specific formulation of the equation is

$$(6\text{-}18)\quad \Delta W_{h,t}^{f} = \gamma_{ht}^{f} + \sum_{g=1}^{H} \gamma_{hg} \cdot \Delta \ln r_{g,t}^{w} + \gamma_{hZ} \cdot \Delta \ln Z_{t}^{f} + \sum_{k=1}^{K} \gamma_{hq_k} \cdot \Delta \ln q_{k,t}^{f} - \eta_h \cdot \hat{e}_{h,t-1}^{f} + u_{h,t}^{f}$$

where the $\hat{e}_{h,t-1}^{f}$-term is the residual from the cointegrating regression, and the other variables are similar to those in expression (6-17), except that they are here expressed as first-order differences.

Results of this estimation, using within-groups estimators, are shown in table 6.6.

Ad 5. evaluate the model

As the variables in the error correction equations estimated in step 4 are all stationary, the estimated equations can be evaluated by various standard test procedures and diagnostics. In the current study, we test for goodness-of-fit (by means of R^2), heteroscedasticity (by means of Breusch-Pagan's test) and autocorrelation (by means of a Generalised Durbin-Watson statistic). Results of these tests for crop farms on loamy soil are shown in table 6.7.

In general, the test statistics do not indicate serious many specification problems with the estimated error correction equations, although a few exceptions can be found (the transformation between different roughage areas, which are negligible on the considered crop farms). It should however be kept in mind that the applied statistics are not very powerful, given the relatively limited amount of data.

Table 6.6. Estimated coefficients in selected error correction models, crop farms on loamy soil

	Model B $S_{pig}/(S_{pig}+S_{plt})$	Model C $S_{rgh}/(S_{rgh}+S_{csh})$	Model D $S_{grf}/(S_{grf}+S_{fbt})$	Model E $S_{grn}/(S_{grn}+S_{root})$	Model F $S_{rgs}/(S_{rgs}+S_{pgs})$	Model H $S_{crl}/(S_{crl}+S_{prp})$	Model I $S_{brl}/(S_{brl}+S_{wht})$	Model J $S_{pea}/(S_{pea}+S_{rap})$
$r_{pig\text{-}poult.}$	0.2295 (0.0819)	-	-	-	-	-	-	-
$r_{rough.\text{-}cash}$	-	0.0176 (0.0064)	-	-	-	-	-	-
$r_{green\text{-}fbeet}$	-	-	0.0669 (0.0072)	-	-	-	-	-
$r_{grains\text{-}root}$	-	-	-	0.1067 (0.0327)	-	-	-	-
$r_{rot.\text{-}perm.}$	-	-	-	-	6.0061 (0.4675)	-	-	-
$r_{cer.\text{-}puls/rap}$	-	-	-	-	-	0.2880 (0.0865)	-	-
$r_{sp.barl\text{-}wheat}$	-	-	-	-	-	-	0.2605 (0.1099)	-
$r_{peas\text{-}rape}$	-	-	-	-	-	-	-	0.5973 (0.8107)
ln Z	-	-	-	-	-	-	0.1054 (0.0635)	-
ec.size	0.8139 (0.1289)	-	-	0.0634 (0.0163)	-	-0.1523 (0.0374)	-0.1877 (0.0770)	-1.4763 (0.7146)
crop share	-	-	-	-	-0.3886 (0.1836)	-	-0.4984 (0.2688)	-
Cattle share	-	-	-	-	-0.7099 (0.3142)	-	0.7925 (0.3224)	-58.5391 (29.4589)
D92	-	-	-0.0413 (0.0152)	-	-	-	-	-
eff.prox1 (ovdb)	-	0.0168 (0.0038)	-	-	-	0.0116 (0.0049)	-0.0252 (0.0039)	-
eff.prox2 (ovhs)	0.0115 (0.0052)	-	-	-0.0001 (0.0006)	-	-	-	-
eff.prox3 (lonevn)	-	-0.0011 (0.0002)	-	-	-	-	0.0007 (0.0001)	-
adjustm. pa-ram.	-1.0777 (0.1795)	-0.1022 (0.3747))	-1.9104 (0.3610)	-0.9424 (0.1166)	-0.6584 (0.1091)	-0.8265 (0.2272)	-1.1537 (0.1122)	-
const	-	-	0.2782 (0.0292)	0.1976 (0.0615)	-	0.0228 (0.0122)	-	-

Note: Standard deviations in parentheses

An economic interpretation of the estimated equations can be obtained by transforming the estimated parameters to elasticities of transformation, cf. expression (6-14), using the parameter estimates obtained from estimating expressions (6-17) and (6-18), respectively. In table 6.8 are shown the derived long-run elasticities of transformation for the 8 farm types.

Table 6.7. Diagnostic tests for error correction equations, crop farms on loamy soil

Model	R^2	Breusch-Pagan	Generalised Durbin-Watson
A: Landbased – nonlandb.	0.621	0.262	1.727
B: Pigs – poultry	0.809	0.847	2.565
C: Roughage - cash crops	0.681	-	-
D: Green fod. - fodder beet	0.651	0.000	0.269
E: Grain crops - root crops	0.445	0.776	1.672
F: Rot. grass - perm. grass	0.649	0.000	2.614
G: Potatoes - sugar beets	-	-	-
H: Cereals - pulses/rape	0.440	0.958	1.536
I: Spring barley - wheat	0.749	-	-
Spring barley – winter barley	0.576	-	-
J: Peas - rape	0.349	0.678	1.932

Notes. Breusch-Pagan statistic indicates propability of homoscedasticity " – " means that there were too few observations to calculate the statistic.

Table 6.8. Nested long-run elasticities of transformation

	Crop, loam	Crop, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Par-time, loam	Part-time, sand
Landbased – nonlandb.	^	0.254	^	^	0.312	0.298	-	-
Pigs – poultry	0.066	-	^	^	-	-	-	-
Roughage - cash crops	1.522	^	0.219	0.263	-	^	-	0.369
Green fod. - fodder beet	9.127	5.499	-	0.544	10.428	6.255	13.387	0.958
Grain crops - root crops	0.021	0.738	0.363	4.495	-	-	-	-
Rot. grass - perm. grass	32.201	37.373	-	200.628	94.135	21.440	-	51.014
Potatoes - sugar beets	-	-	-	-	-	-	-	-
Cereals - pulses/rape	2.549	0.849	-	3.811	1.219	0.201	-	0.886
Spring barley - wheat	0.381	-	0.416	0.963	1.350	2.397	-	-
Peas - rape	4.106	-	-	3.906	-	0.447	-	-

Note: "-" indicates elasticities which could not be estimated due to insufficient data material, "^" indicates that elasticities were negative and hence do not make economic sense.

For example, the long-run elasticity of transformation between roughage and cash crop production for crop farms on loamy soil is 1.522, implying that a one per cent increase in cash crop profits relative to that of roughage production will lead to a 1.522 per cent increase in the ratio between cash crop and roughage area in the long run. For pig farms on sandy soil, a one per cent increase in the profitability of aggregate pig/poultry production relative to that of aggregate landbased activity will lead to a 0.298 per cent increase in the ratio between pig/poultry activity and area, i.e. the number of animals in these two livestock categories per hectare.

In general, there appears to be a high elasticity of transformation between different types of roughage, and also between peas and rape. For some farm types, there are also relatively high transformation elasticities between cereals and other grain crops. The elasticity of transformation between landbased (crops and cattle) on the one hand and non-landbased (pigs and poultry) on the other – as well as between cash crops and roughage - are relatively small. There does not seem to be any systematic pattern between the sizes of elasticities on loamy and sandy soils, respectively.

From the estimated error correction equations, short-run elasticities of transformation can be derived on the basis of expression (6-15). These are shown for the 8 farm types in table 6.9.

Table 6.9. Nested short-run (one-year) elasticities of transformation

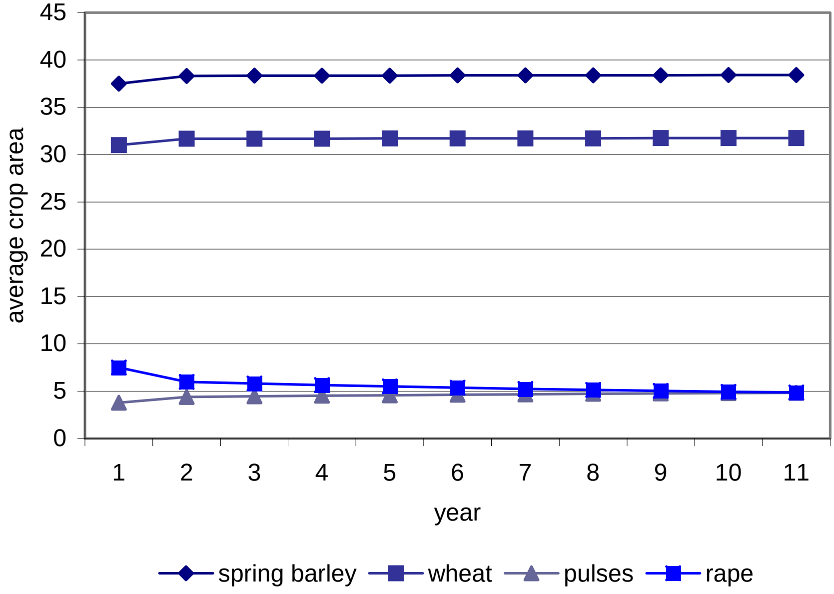
	Crop, loam	Crop, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Part-time, loam	Part-time, sand
Landbased - non landbased	-	-	-	-	0.223	0.002	-	-
Pigs - poultry	0.047	-	-	0.033	-	-	-	-
Roughage - cash crops	-	-	-	-	-	-	-	-
Green fodder - fodder beets	-	-	-	-	-	-	-	-
Grain crops - root crops	-	1.086	0.801	-	-	-	-	-
Rot. grass - perm. grass	29.655	13.962	0.000	195.94	55.767	28.172	-	41.294
Potatoes - sugar beets	-	-	-	-	-	-	-	-
Cereals - pulses/rape	1.248	1.327	-	1.211	2.429	0.007	-	1.264
Spring barley - wheat	0.035	-	0.648	0.955	1.769	2.522	-	-
Peas - rape	1.395	-	-	2.847	-	3.286	-	-

Note: "-" indicates elasticities which could not be estimated due to insufficient data material, "^" indicates that elasticities were negative and hence do not make sense in economic analysis.

The interpretation of the elasticity estimates in table 6.9 is similar to those in table 6.8, except that the time horizon is shorter. Whereas the lon-run elasticties represent the entire adjustment towards a new long-run equilibrium, the short-run elasticities represent the part of this adjustment taking place within the first year. Although the elasticities of transformation are in general smaller in the short run than in the long run, as expected, the pattern of elasticities seems to be similar to that of the long-run elasticities. Hence, we find relatively large elasticities of transformation between different roughage areas, and fairly modest elasticities between land-based and land-independent activities.

The model also determines the path of adjusting the composition of activities given a change in the relative profitabilities in the various sub-sectors. Assuming that initial activity levels reflect a long-run equilibrium, and abstracting from the trend development of this equilibrium, this adjustment can be illustrated by the following example, considering a permanent 20 per cent drop in the economic returns to rape production and holding all other returns constant. From year 1 to year 2, only the short-run effects as described in table 6.9 have impacts on the activity levels. In year 2, producers observe that their activity levels have deviated from the long-run equilibrium (which has been affected by the drop in rape returns, as determined by the elasticities in table 6.8). Thus, from year 2 to 3 they make an adjustment in their activity composition in order to approach the new long-run equilibrium. On the other hand, as there is assumed no change in economic returns during this period, there are no short-run effects. From year 3 to 4, they further adjust acitivity levels towards long-run equlibrium etc. The changes in activity levels in some of the most affected sectors (spring barley, wheat, pulses and rape) for crop farms on loamy soil are shown in figure 6.3.

Figure 6.3. Change in activity levels for four crops due to a 20 per cent drop in rape returns, crop farms on loamy soil



As expected, the area with rape decreases due to the drop in relative economic returns, and other crop areas increase. It is worth noting that the major part of the activity adjustments take place within the first couple of years.

Finally, we can derive approximate expressions for elasticities representing the responses in individual activity levels due to changes in the total area.

(6-19) $$\frac{\partial z_h}{\partial Z}\frac{Z}{z_h} \approx 1 + \frac{\partial W_h}{\partial Z}\frac{Z}{W_h} = 1 + \frac{\alpha_{hZ}}{Z}$$

These elasticties can be calculated taken into account the nesting structure outlined in figure 6.2 and using the long-run coefficient estimates in table 6.4, or the short-run coefficient estimates in table 6.6. Such elasticities representing the long run are shown in table 6.10.

Table 6.10. Long-run elasticities between total area and individual activity levels

	Crops, loam	Crops, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Parttime, loam	Parttime, sand
Spring barley	1.44	0.92	0.60	0.80	2.42	2.13	1.00	1.19
Winter barley	1.44	0.92	0.93	0.74	1.35	1.00	1.00	1.19
Wheat	1.44	0.92	1.26	0.80	0.29	-0.13	1.00	1.19
Pulses	1.16	0.92	0.93	1.15	0.65	0.73	1.00	0.81
Rape	1.73	0.92	0.93	1.15	0.65	1.27	1.00	0.81
Potatoes	1.44	0.44	0.93	0.98	1.00	1.00	1.00	1.00
Sugar beets	1.44	0.44	0.93	0.98	1.00	1.00	1.00	1.00
Fodder beets	0.56	1.17	1.19	1.06	1.00	1.00	1.00	1.00
Rot. greenfodder	0.59	1.17	1.19	1.08	1.00	1.10	1.00	1.17
Permanent grass	0.52	1.17	1.19	1.37	1.00	0.90	1.00	0.83
Fallow	1.00	0.93	1.06	1.06	1.00	1.00	1.00	1.00
Dairy cattle	0.56	1.17	1.19	1.16	1.00	1.02	1.00	1.03
Beef cattle	0.56	1.17	1.19	1.16	1.00	1.02	1.00	1.03
Pigs	1.00	1.07	0.94	0.94	1.00	1.00	1.00	1.00
Poultry	1.00	1.07	0.94	0.94	1.00	1.00	1.00	1.00

Note: parameters, which could not be estimated, are assumed zero

The elasticities in table 6.10 represent the percentage change in specific activity levels, if the total area increases by one per cent. For example, if the total area on crop farms (loam) increases by one per cent, the area with cereals increase by 1.44 per cent, where as the area with fodder beets increases by only 0.56 per cent. These elasticities depend on the estimated coefficient to total area, Z, cf. table 6.4. As the coefficient to total area was insignificant in e.g. the sub-model for allocation of cereals area (submodel I for crop/loam farms), the derived effect of an increase in total area is proportional for all cereals.

The elasticities show some variation in area sensitivity across farm types. Whereas crop farms on loamy soil expand their cash crop activity more than proportional to an increase in the total area available, cattle farms increase their cash crop area less than proportional to a general area increase. Crop farms on sandy soil increase roughage areas more than proportional to a general area increase (represented by the elasticity 1.17), which may seem surprising, taking into account the milk quota restriction on cattle production.

6.5. Discussion

This chapter documents the construction of a model for determining activity levels in the respective agricultural sub-sectors. The model is based on panel data from Danish farm accounts and constructed in a dynamic setting, which is considered to be relevant for analysing adjustments in land use and livestock activity. Such adjustment processes normally take time due to biological restrictions, farmers' skills, risk aversion etc.

The analysis has resulted in econometrically estimated behavioural parameters for land allocation and livestock activity levels, in the short and the long run, including the adjustment towards restoring long-run equilibrium, for eight farm types. In general, the estimated models have demonstrated reasonable explanatory power and no dramatic problems with e.g. heteroscedasticity and autocorrelation. Some variation is observed across farm types, especially with respect to the allocation between cash crops and roughage, which seems to be less elastic on cattle farms than on other farms. Some variation betweeen soil types is also observed with respect to grains versus other cash crops. For root crops versus grains, the transmission seems to be most flexible on sandy soil, whereas the transmission between cereals and peas/rape seems most flexible on loamy soil. From a first impression, most of the resulting behavioural parameters seem reasonable.

However, it must be noted that due to relatively short lengths of panels in the data set, the estimated dynamic properties are subject to some uncertainty. Where most applied tests for unit roots, cointegration etc. would prescribe at least 20-30 observations per farm, only 6-10 observations were available in the present dataset. Data from farms, which have been in the panel for at least 6 years, have provided the basis for the results presented in this chapter. Sensitivity analysis with respect to this delimitation has been conducted (using 5 and 7 years as alternative criteria), showing that the results are fairly robust to such changes.

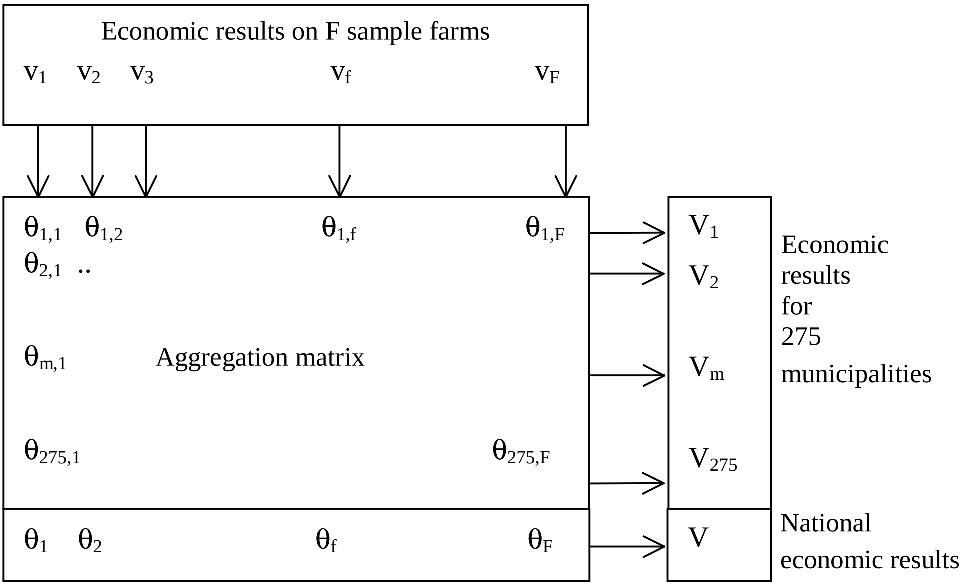
One important consequence of this data shortcoming is likely to be that the extent of disequilibrium is underestimated, and hence farmers' adjustments (and needs for adjustments) are underestimated. The model may be too 'conservative' in describing farmers' determination of activity level in the respective lines of production.

It should also be noted, that the estimated models build on a number of structural assumptions and approximations. One set of assumptions is the imposed separability structure, which may be justified from considerations concerning the differences in the structural aspects in switching between different agricultural activities (e.g. between crop and livestock production or between cattle and pig production). Another assumption is the separability in the profit function, imposed in expressions (6-9) and (6-11), which implies that the sub-sector activity terms can be excluded from the sub-sector profitability measures. This assumption has the important tractability implication that the variation in relative economic returns in the respective subsectors can be represented by average measures. To the extent that economic returns in individual agricultural sub-sectors depend on the farms' specific composition of activities (for instance because production of one crop influences the economic returns in other crops due crop rotation effects), this may be an over-simplification. However, this problem is not considered to be serious in the present context, where results are interpreted at the farm type level – not the individual farm level.

7. Aggregation from farm level to national and municipality level

The previous chapters have focused on the determination of input composition, yield levels and the use of capital and land at the farm level. These farm level results can be transformed to aggegate results by using an aggregation scheme. This chapter describes an aggregation scheme, which enables aggregation from farm level to more aggregate levels (national and municipality level), and hence makes it possible to calculate effects of various scenarios at these levels of aggregation. The main principle in the aggregation to municipalities is illustrated in figure 7.1.

Figure 7.1. Aggregation of farm data to municipalities



The determination of aggregation scheme is performed in two steps. In the first step, factors to aggregate the sample data to the national level are determined, and in the second step, these national aggregation factors are distributed to municipalities.

7.1. Aggregation to the national level

For a given year, the accounts database consists of account data from a sample of 1500-2000 farms, cf. chapter 3. To each of these sample farms, an aggregation factor is attached, reflecting the individual representativity of the specific sample farm. For example, if the aggregation factor attached to sample farm no. f (θ_f) is 30, this sample farm could be considered to represent 30 farms in the population of Danish farms. Hence, if a variable v is represented in the farm account data, an estimate of the corresponding aggregate (national) variable V, can be obtained by the expression[25]

(7-1) $$\hat{V} = \sum_f \theta_f v_f$$

A set of aggregation factors to aggregate the sample data to the national level have been constructed using a minimum cross-entropy approach[26]. The basic idea is to determine robust aggregation factors, which ensure consistency with official aggregate figures concerning a number of structural variables, e.g. the number of farms in different categories, numbers of hectares with diffent crops, numbers of animals in different livestock categories, etc. at a national, county and municipality level. The aggregation factors are the solution to an optimisation problem, where the cross-entropy function

(7-2) $$\Phi = \sum_{f=1}^{F} \theta_f \cdot \ln(\theta_f / \theta'_f)$$
$$\sum_{f=1}^{F} \theta_f = N, \; \sum_{f=1}^{F} \theta'_f = N, \;\; \theta_f, \theta'_f > 0 \quad \text{all } f$$

is minimised with respect to the aggregation factors $\theta_f \; (f = 1,...,F)$ for given preliminary values of the aggregation factors, $\theta'_f \; (f = 1,...,F)$. These preliminary factors are available in the accounts database. In general, the cross-entropy function becomes smaller, the more similar the θ_f-factors are to the set of preliminary factors, θ'_f. The cross-entropy function is minimised subject to a number of restrictions representing the above-mentioned structural variables

(7-3) $$V \cdot (1-e) \le \sum_f \theta_f \cdot v_f \le V \cdot (1+e)$$

25 See Hansen (1999, chapters 2 and 3) for an introduction to the aggregation scheme.

26 This approach to generate aggregation factors has been developed by Jacobs (1998) and applied by Osterburg et al. (2000).

where the e-term allows for some deviation from the population data. Experiments determine the minimum feasible value of e. The restrictions in (7-3) ensure consistency with known totals, whereas minimisation of the objective function in (7-2) yields the maximum robustness in the set of aggregation factors, i.e. the sensitivity of the aggregation scheme to changes in the sample size is minimised. The determination of aggregation factors will be described in more detail in Andersen (2002).

7.2. Distribution of the national aggregation to the municipality level

Having determined aggregation factors at the national level, we need to distribute these factors to the municipality level. Two approaches have been considered for that purpose:

- a least-squares approach, which is relatively tractable, and
- a maximum entropy approach, along the lines described in section 7.1, but at the municipality level.

The following focuses on the least-squares approach, which is the one actually used[27]. Least-squares construction of municipality aggregation factors proceeds in two steps. In the first step, a matrix A of preliminary weights are calculated, and in the second step, these preliminary weights are adjusted in order to take into account for the specific production structures in different municipalities.

When calculating *preliminary aggregating factors*, a B_{275x14}-matrix is first calculated, where the individual elements in B are given by the expression

(7-4) $$b_{ms} = \frac{n_{ms}}{\sum_k n_{ks}}$$

b_{ms} represents municipality no. m's share of the total number of farms in farm size category s (of which 7 size groups on loamy soil and 7 size groups on sandy soil), where n_{ms} is the number of farms of category s in municipality m. Index k runs over

[27] The maximum entropy approach has also been attempted at the municipality level, but has not been completed within the time horizon of the current project. Using the maximum entropy approach for this purpose implies simultaneous determination of a very large number of aggregation factors, and such a big problem takes a significant amount of computer time to solve. It will be described in more detail in Andersen (2002).

municipalities. Next, the preliminary $A_{275x2000}$ aggregation matrix is calculated, based on the constructed B-matrix. Individual elements in the A-matrix are given by the expression

(7-5) $$a_{mf} = a_f \cdot b_{ms(f)}$$

where a_{mf} represents sample farm no. f 's preliminary aggregation factor in municipality m, a_f represents the national aggregation factor attached to sample farm f, and $s(f)$ represents the relevant farm category number (referring to the B-matrix) for sample farm f. Hence, the procedure in (7-5) provides a municipality distribution of the national aggregation factor attached to sample farm f.

The above distribution is done solely on the basis of the respective municipalities' shares of farms within the different farm categories taking the farms' area and soil type into account, whereas the production structure in the individual municipalities was not considered. In the second step, these preliminary aggregation factors are *adjusted for municipality-specific production structures*. For municipality m, the approximated aggregated vector of structural variables $\hat{V}_m$ can be calculated by $\hat{V}_m = \sum_{f=1}^{F} a_{mf} v_f$, where v_f is the corresponding vector of structural variables on sample farm f, and a_{mf} is the preliminary aggregation factor for sample farm f in municipality m. This aggregated vector $\hat{V}_m$ may be relatively different from the "true" vector of structural variables in municipality m, V_m. For example, one can imagine that the livestock density in a western municipality with sandy soil is underestimated, when these preliminary aggregation factors are applied. See table 7.2 for an assessment of the preliminary aggregation at the county level.

Thus, the purpose of the subsequent adjustment is to ensure a better accordance with the structure of agriculture distributed on counties, as it can be observed in the official statistics[28]. This is done by introducing a matrix of adjustment factors C into the above expression, thus obtaining

(7-6) $$\tilde{V}_m = \sum_{f=1}^{F} a_{mf} c_{mf} v_f$$

where c_{mf} represents the adjustment factor when sample farm f is used for representing agriculture in municipality m. If the adjustment is successful, the obtained ag-

[28] The applied approach is inspired by Hansen (1999).

gregated vector of structural variables should be fairly close to the true vector for municipality m, V_m. Hence, a way to formulate the adjustment problem is to minimize the sum of squared deviations.

(7-7) $$(\tilde{V}_m - V_m)'(\tilde{V}_m - V_m)$$

with respect to the vector of c_m's referring to municipality m, and perform this minimization procedure for each municipality.

A problem with this approach in its unrestricted form is that the number of adjustment factors to be estimated exceeds significantly the number of observations available for this estimation. However, this problem can be overcome by imposing restrictions on the c's, i.e. impose mutual bindings on some of the c-coefficients. These restrictions are imposed by assuming equal adjustment (c-) coefficients for model farms sharing certain criteria, for instance main production, acreage, etc. Each group of weights is hereafter to be adjusted with a common adjustment factor $c_{mg(f)}$, where $g(f)$ maps the individual sample farms into a smaller number of farm groups, where farms within a group are given the same c-factor. In the present application, farms are grouped according to acreage (above or below 30 ha), grain production's share of total acreage (above or below 50 per cent), main production (crops, cattle, pigs/other), number of animals (0-50, 50-100 or above 100 Livestock Units), as well as 12 regions/counties.

The determination of aggregation factors at the municipality level involves restrictions on the national, county and municipality level[29]. The matrix of preliminary weights A, the data material in the account statistics concerning the sample farms, v_f, and in Statistics Denmark's aggregate information at the county level, $V_M = \sum_{m=1+m_{M-1}}^{m_M} V_m$ (where the municipalities in county M are indexed $1+m_{M-1},\ldots,m_M$), provide the informational basis for estimating the adjustment coefficients $c_{g(f)}$. As mentioned above, the adjustment coefficients should in general ensure the best possible correspondence between the observed values of the structural variables and the estimated (aggregated sample data) structural variables. Imposition of restrictions at the national level is similar to that described in expression (7-3), restrictions

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[29] It might be expected that only municipality level restrictions were relevant. However, due to data limitations (especially at the municipality level), we use county data to reflect regional differences.

at county or municipality levels are slightly different. At the county level, restrictions can be represented by the expression.

(7-8) $$V_M = \sum_{m=1+m_{M-1}}^{m_M} \sum_f a_{mf} \cdot c_{mg(f)} \cdot v_f + e_M$$

The error term e_M allows for deviations between the estimated and true aggregate V 's. The main idea is to determine $c_{mg(f)}$ –coefficients, which minimise these deviations in absolute terms, and this problem can be solved by a least squares methodology. The estimation procedure is formulated as a quadratic programming problem, where correspondence in some of the variables (e.g. total number of farms and total agricultural area) is considered to be more important than in other structural variables (e.g. land allocation and livestock numbers). This is handled by double-squaring these errors and giving them extra weight in the objective function. The V -vectors contain 13 elements (structural variables - acreage of cereals, pulses, rape, root crops and grass in rotation as well as the number of dairy cows, nurse cows, heifers, male calves, pigs for breeding and piglets and slaughter pigs, plus the number of farms and the total agricultural area), some variables at the municipality level (area data), and others only at the county level[30]. Similarly, for each of the sample farms, 13 corresponding structural variables are included in the v_f -vector. The $c_{g(f)}$'s are defined as one plus an error term, which in the objective function is squared. This is done to suppress extreme solutions.

A problem with the formation of the observations is that the designations for and division of crops in the SJFI account statistics and the Statistics Denmark's data are not identical. To the extent that the used correspondence does not reflect the actual connection in the statistics, this will lead to incorrect estimation of the factors adjusting the weights. However, we do not consider this to be an important problem in the current context.

Evaluation of the adjustment

In order to evaluate whether the adjustment improves aggregation, the performances of aggregation with unadjusted and adjusted factors, respectively, have been compared,using data for 1995/96. The performance of the two schemes is evaluated by comparing the estimated aggregated figures with those from Statistics Denmark,

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30 The three counties around Copenhagen (Copenhagen, Frederiksborg and Roskilde) are gathered in one county group.

which form the basis for the adjustment. As a basis for the comparison, data on the agricultural production structure in 1995/96 are given in table 7.1.

Table 7.1. Agricultural production structure in Danish counties, 1995/96, 1000

	Cere-als (ha)	Pulses (ha)	Rape (ha)	Root crops (ha)	Grass (ha)	Dairy cows	Nurse cows	Heif-ers	Bulls/bull-calves	Breed-ing pigs	Other pigs
Capital region	70.7	1.1	11.2	2.1	25.1	7.6	4.8	11.5	7.7	18.9	180.6
West Seeland	117.5	2.6	13.5	12.4	36.8	20.9	5.9	25.6	12.4	59.5	604.1
Storstrøm	142.1	1.8	8.8	42.0	29.9	17.1	4.4	18.8	10.1	51.9	489.1
Bornholm	22.2	0.7	3.9	0.6	6.0	5.4	0.8	6.1	3.0	20.6	202.1
Funen	136.9	2.4	14.9	16.5	40.1	52.6	4.4	56.2	17.7	88.4	914.6
South Jutland	136.4	6.2	13.9	11.6	110.1	97.8	13.1	124.0	53.0	108.5	1077.4
Ribe	78.9	5.5	6.6	10.4	97.0	88.5	12.7	111.4	45.5	45.7	475.2
Vejle	104.0	3.8	9.9	8.6	52.7	47.9	9.6	58.0	29.2	88.8	858.5
Ringkøbing	146.9	13.4	13.7	22.5	107.7	103.2	14.2	123.1	62.4	140.4	1399.0
Århus	165.0	6.2	21.7	7.0	66.5	49.4	13.1	64.8	32.0	116.6	1144.3
Viborg	132.7	8.8	13.8	10.1	89.9	85.8	19.7	110.3	58.7	123.9	1221.4
North Jutland	194.2	21.8	19.9	19.3	133.6	126.3	19.7	152.3	71.7	151.8	1502.5

Source: Statistics Denmark

In the two following tables the percentage deviations of estimated aggregate data from the official data of Statistics Denmark are shown, for the unadjusted and adjusted aggregation factors, respectively.

Table 7.2. Deviation between aggregated farm data and observed population data – unadjusted aggregation factors, per cent.

	Cere-als	Pulses	Rape	Root crops	Grass	Dairy cows	Nurse cows	Hei-fers	Bulls etc.	Breed-ing pigs	Other pigs
Capital region	-5	157	-43	-58	57	223	5	166	94	215	161
West Seeland	-2	41	-21	20	28	66	2	60	62	68	34
Storstrøm	3	132	56	-52	60	105	-2	105	97	116	90
Bornholm	-4	-26	-52	370	-19	2	-5	0	5	-15	-29
Fyn	-4	91	-16	4	13	-15	65	-6	44	25	-1
South Jutland	5	30	16	62	-40	-22	-26	-28	-24	11	-11
Ribe	19	17	58	10	-39	-29	-18	-30	-23	82	33
Vejle	-5	23	1	44	-6	-8	-19	-7	-13	-5	-21
Ringkøbing	1	-25	21	-20	-5	-5	15	-1	-7	-5	-28
Århus	-13	19	-31	152	50	40	3	34	27	11	-11
Viborg	-3	-15	-8	47	2	-12	-19	-12	-22	-69	0
North Jutland	-2	-42	8	18	11	-7	9	-3	-6	18	-10

The tables show that the adjustment of aggregation factors in general reduces the deviation from observed levels, especially for pigs and cattle, where the correspondence with the farm's area is less straightforward than for cropping activities[31]. It is also observed from table 7.3 that there is some variation across sub-sectors concerning their goodness-of-fit in the approximation. However, for the three dominating sub-sectors (cereals, dairy cattle and pigs, representing some 75 per cent of the output covered by ESMERALDA) the deviations are relatively small in almost all regions. On the other hand, regional interpretation of model results concerning special production (e.g. sugarbeets, potatoes etc.) should be done with care.

Table 7.3. Deviation between aggregated farm data and observed population data – adjusted aggregation factors, per cent.

	Cere-als	Pulses	Rape	Root crops	Grass	Dairy cows	Nurse cows	Heifers	Bulls etc.	Breed-ing pigs	Other pigs
Capital region	9	67	-49	-68	-18	15	7	25	11	10	2
West Seeland	-4	54	-9	12	-2	11	0	16	24	16	-1
Storstrøm	2	57	25	-42	1	16	2	22	30	11	6
Bornholm	-18	-24	-35	112	-10	-12	-2	-8	3	12	-3
Fyn	-5	55	-19	3	23	9	5	11	32	21	-2
South Jutland	-2	10	0	43	-20	3	-4	-3	3	16	-4
Ribe	5	-1	9	14	-15	-3	-5	-7	-3	9	-7
Vejle	-7	17	0	27	3	3	0	7	5	16	-3
Ringkøbing	0	-8	18	8	-8	-5	-3	-4	-10	19	-12
Århus	-4	8	-24	61	5	-6	3	-4	2	19	-4
Viborg	-5	-11	2	33	4	-10	-7	-8	-15	-60	14
North Jutland	-1	-32	16	31	1	-13	-5	-11	-13	15	-9

As is seen in the table, the resulting adjusted regionally distributed aggregation factors still imply relatively large errors for some of the structural variables at the county level. This is in particular the case for pulses, rape, root crops and beef cattle. On the other hand, the approximation of the most important lines of agricultural production: cereals area, dairy cattle and pig production seems to be quite good at the regional level, with maximum deviations around 10 per cent.

It is possible to reduce the deviations further by relaxing the extreme solution constraint, however at the cost that a large share of the aggregation factors attain values

31 The unadjusted aggregation coefficient is based on an area grouping of farms, cf expressions (7-2) and (7-3).

close to zero, meaning that a large part of the groups of weights nearly are removed from the resulting matrix, and the aggregation matrix becomes less robust.

7.3. Discussion of the aggregation approach

The aggregation scheme outlined in this chapter provides a relatively flexible approach to aggregating farm level results to the desired aggregated level, be that the national, municipality or specific groupings of farms, e.g. according to farm size, main production etc. At the same time, it provides an approach to decompose aggregate results into different farm groupings. The latter feature is useful, when applying the model in connection with other analytical tools, e.g. macroeconomic models.

There are however two problems with the aggregation scheme. The first problem, to which a couple of solutions have been proposed in this chapter, is the question of providing data for constructing the aggregation matrix. Provided structural data for the desired "populations", the methods described above can be used for constructing an aggregation matrix. Such structural data are relatively easily available at the national (and county) level, but are more sparse at more disaggregated levels. Hence, the constructed aggregation factors cannot be more precise than the structural data, on which the calculation of these aggregation factors is based.

The second problem is that the aggregation matrix is a static representation of the farm structure at a given point in time. As the farm structure is rapidly developing (towards fewer, larger and more specialised farms), the aggregation factors must be adjusted for this development, if the model is used for, e.g. projections of future developments. See Andersen (2002) for treatment of this problem within the current model framework.

8. Discussion and perspectives

The purpose of the developed model ESMERALDA has been to establish a tool for quantitative economic assessments of developments and policy initiatives related to the agricultural sector, with special emphasis on regional diversities within the agricultural sector.

The model development effort has had three specific aims:

1. economic analysis of changes in the Danish agricultural sector at the national and local level
2. easy integration with other economic model tools in order to enable holistic economic analysis
3. easy integration with environmental satellite models for analyses of interactions between economics and environment related to agriculture

Ad 1. Economic analysis at the national and regional level

The constructed model takes a farm-level point of departure, with subsequent aggregation to any relevant aggregated level. At the farm level, three types of impacts are considered: input substitution effects, production intensity effects and activity adjustment effects on approximately 2000 sample farms.

Input substitution effects reflect the economic incentives to replace more expensive inputs with cheaper inputs, when relative input prices change, for a given activity and intensity levels. For example, an increase in the price of commercial fertilisers will make it more profitable to increase the efforts to improve the utilisation of animal manure and hence reduce the need for commercial fertilisers.

Production intensity effects reflect the economic incentive to adjust e.g. the planned crop yield per hectare, when the relation between output and input prices changes. These effects are to some extent comparable with effect assessments based on crop yield functions from field experiments (e.g. Rude, 1991), although there are also some conceptual differences.

Activity effects reflect the incentives to change allocation of land and numbers of animals, when the relative profitability changes: farmers will change activity composition towards activities relatively favoured by e.g. price changes at the cost of activities relatively disfavoured.

This decomposition of effects is useful for the interpretation of results, as well as the comparison with other (partial) assessments of some of the effects. For example, estimates indicate that a major share of farmers' response to higher fertiliser prices, in terms of reduced application of commercial fertilisers, is due to input substitution. This effect dominates the effect of crop yield adjustment. It should be noted that the estimated long-run effects on land allocation and livestock activity levels are subject to more uncertainty than is the case with the short-run behavioural parameters, due to the relative short lenghts of panel observations.

Aggregation of farm-level results to the relevant level is based on an aggregation matrix, with a set of aggregation factors attached to each model farm. This provides a fairly flexible scheme for representing various populations of farms, e.g. municipalities, farm size groups, etc.

The model has been used for scenario analyses, where the impacts of various changes in the economic conditions for agriculture are altered (see Jensen, 2002). The analyses comprise the national and regional (county) level, but also illustrates the variation between individual farms. Furthermore, the model has been used for spatial economic analysis, investigating the economic potentials for aforestation and drinking water protection within a specific study area in Denmark (see Rygnestad et al., 2000).

Ad 2. Integration with other economic models

The aggregation scheme in the model establishes a link between the relatively disaggregated level of analysis at the farm and product level and more aggregated analysis at the national level. This feature enables integrating farm-based analysis of agricultural changes with analysis of their impacts on other industries, consumers etc., in a macroeconomic setting. Some of the methodology for establishing such links has been developed by Jensen et al. (1999), and it has been used in relation to the macroeconometric ADAM-model in order to improve the environmental assessment of macroeconomic projections (see Jensen et al., 2001, and Andersen et al., 2001). Furthermore, the model has been used in relation to an Applied General Equilibrium model (the AAGE-model, see e.g. Jacobsen, 2001) and local macroeconomic model (the LINE-model, see e.g. Madsen, 1999) for scenario analyses concerning the economic development for rural municipalities in Denmark (see Hasler et al., 2002).

Ad 3. Integrated economic and environmental analysis

The farm-level basis for the model has proven useful for analysing a wide range of environmental policy instruments, because it enables taking into account the diversity among Danish farms when analysing farm-oriented instruments. However, as the main data foundation for the model has been economic accounts data (where the use of e.g. fertilisers and pesticides have been represented at a relatively aggregated level), the model so far has some limitations in these respects. This poses a problem when applying the model for environmental assessments, because the links between the costs to aggregate fertilisers and pesticides and the specific environmental strains are relatively weak.

Some effort, building on various approximation techniques, has been done in order to remedy this problem. Huusom (2001) has developed a method for providing physical pesticide quantity data, which can be integrated into the model, and in Jensen et al. (2001), this has been supplemented with the construction of nitrogen balance data – also compatible with the ESMERALDA framework. Jørgensen & Jensen (2000) have estimated disaggregated price elasticities for individual components of fertiliser and pesticide use, supplementing the available accounts data with agronomically motivated theoretical assumptions concerning the technological structure with respect to these inputs. Thus, a framework exists for using the model for environmental analysis. Although these results may be considered as the best possible alternative under the given data circumstances, it is still important to keep in mind, that they could be improved if the necessary data were available.

Perspectives for further development

As the above examples demonstrate, the scope for analyses with the ESMERALDA model is relatively broad. In its current form, the model framework is fairly well-suited for economic analyses of scenarios concerning agricultural and agri-environmental policy initiatives and instruments. Such instruments include market-oriented measures (e.g. price changes, taxes, general support schemes) as well as farm-oriented measures (targeted support schemes or regulations, conditional regulations or premia etc.). Hence, the model is designed to cover most of the policy measure types considered in current policy-making of relevance to the agricultural sector. As indicated above, however, there is room for improving the model's description of linkages between economy and specific environmental indicators (e.g. nitrate leaching), either by supply of more well-suited data or by integrating existing information from other sources to a higher extent than has already been the case. This would also include an improved representation of, what happens if we consider "radical" scenarios, e.g. a total ban on pesticide use, introduction of new technologies etc.

Furthermore, the model is suited for contributing to economic projections of the agricultural sector, provided exogenous information from other sources. In its present form, the aggregation scheme is static and so does not explicitly take into account changes in the farm structure. Provided an exogenous projection on the farm structure, the aggregation scheme can however be calibrated to be compatible with this projected structure. Hence, projections with the model in it's current form requires exogenous projections of the farm structure. It would however be desirable to integrate productivity and farm structure developments in the model, as these developments must be expected to be closely connected to the development in economic conditions on different farm types.

Finally, some of the recent trends in food and agricultural policies in many industrialised countries include an increased emphasis on food quality and food safety. This emphasis raises the need for addressing product differentiation in agricultural production, in terms of different qualities of the same basic food component, e.g. an organic and a conventional version of milk, meat, cereals etc.

The model described in the current report is the result of a relatively large research effort, and as mentioned above, the model has demonstrated it's usefulness for many different types of analyses, for example in relation to regional aspects. As with any economic modelling effort, there is still room for improvement and development, and also significant future gains to be harvested from such improvements, in terms of relevant and precise quantitative economic analyses related to the agricultural sector.

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Appendix A. Notational conventions

w_i:	variable input price number i (gathered in the vector w)
p_h:	variable output price number h (gathered in the vector p)
x_i:	quantity of variable input number i at the farm level (gathered in the vector x)
Y_h:	quantity of variable output number h at the farm level (gathered in the vector Y)
y_h:	yield level (i.e. output per activity unit) in sub-sector h.
z_h:	activity level (number of hectares or animals) in sub-sector h at the farm level
q:	vector of quasi-fixed variables
Z:	total area at the farm level
C:	total variable costs at the farm level
S_i:	variable input number i's share of total variable costs at the farm level
S_{yh}:	output-cost ratio for sub-sector h at the farm level
Π:	total long-run profit at the farm level
t:	time-index, trend variable
f:	farm-index
I:	total number of variable inputs
H:	total number of outputs/sub-sectors
ε_{ij}:	price elasticity (effect on input no. j due to change in price no. i) (gathered in the matrix E)
r_h:	economic returns pr. activity unit in sub-sector h
σ_{hg}:	elasticity of transformation between subsectors h and g
α_{ij}:	parameters in the short-run translog cost function (gathered in the matrix A)
θ_f:	aggregation factor for farm no. f
A:	auxiliary matrix in calculating municipality-distributed aggregation factors
B:	matrix of preliminary aggregation factors to municipalities
C:	matrix of adjustments to municipality aggregation factors

F:	number of farms
m:	municipality index
s:	farm structural group index
v_g:	unspecified variable at the farm level
V:	unspecified variable at the aggregate level
e,u,v,μ,ν:	stochastic error terms
I_k:	identity matrix with dimension k

Appendix B. Estimation results for input demand equations

Table B.1. Crop farms on loamy soil

Explanatory variables	Energy	Labour	Fertilizer	Pesticides	Services	Roughage
Price variables (logs)						
Energy price	0.0356	-0.0348	0.0123*	-0.0084		
Wage rate	-0.0348	0.2597	-0.0510	-0.0767		
Fertilizer price	0.0123	-0.0510	0.0420	0.0290		0.0058
Pesticide price	-0.0084	-0.0767	0.0290			0.0028$^{\otimes}$
Pig feed price		0.0875*				
Cattle feed price						-0.0109
Services price					0.0511	-0.0154
Roughage price			0.0058	0.0028	-0.0154	0.0063*
Activity levels (logs)						
Spring barley						
Winter barley	-0.0005$^{\otimes}$					
Wheat			0.0009*			
Pulses						
Rape						
Potatoes						
Sugar beets						0.0015
Dairy cows	0.0005*					
Beef cattle			-0.0018		-0.0007*	0.0006
Pigs	-0.0004*		-0.0036	-0.0014		
Poultry		-0.0075			-0.0007*	
Fodder beets				0.0020*		-0.0005
Grass in rotation		0.0032				
Perm. grass	-0.0005					0.0002*
Fallow		0.0037		-0.0025	0.0008	
Yield levels (logs)						
Spring barley			0.0041*		-0.0024$^{\otimes}$	
Winter barley						
Wheat				0.0020*	-0.0022	
Pulses				0.0010	-0.0009	
Rape			0.0012	-0.0006*	0.0007*	-0.0001*
Potatoes				-0.0032*	0.0054	
Sugar beets	-0.0011		-0.0029	0.0015		-0.0020
Dairy cows		0.0095				0.0008
Beef cattle				-0.0055		0.0010
Pigs		-0.0258		-0.0094		-0.0009$^{\otimes}$
Poultry		-0.0195				0.0004
Other variables						
Equipment (log)	0.0081			0.0076	-0.0167	
Buildings (log)		-0.0171			0.0062	
Time-trend		-0.0097	-0.0030	0.0062		0.0006
Standard Gross Margin (log)		0.0524*				
Crop share	0.0459	0.2976	0.2880	0.1725	0.0700	-0.0124
Cattle share				0.0546$^{\otimes}$	0.0973	
Climate			0.0596			0.0037$^{\otimes}$
Farmer's age	-0.0002*		0.0003*			0.0001
Effiency-proxy 1						
Effiency-proxy 2	-0.0007			0.0020	-0.0022	
Profitability	0.0000	-0.0001			0.0001	
INVSDB		-1600.2726	258.7511	422.1593		
INVSQSDB		52.5017	-8.8290	-11.5813		
Observations in the sample						1490
Cohorts in the sample						438

Note: Parameters with no indication is significant at the 1 percent level or below, * indicates significance at the 5 per cent-level and $^{\otimes}$ indicates significance at the 10 per cent level.

Table B.2. Crop farms on sandy soil

Explanatory variables	Energy	Labour	Fertilizer	Pesticides	Services	Roughage
Price variables (logs)						
Energy price	0.0437	-0.0341				
Wage rate	-0.0341	0.1698	-0.0541	-0.0550		
Fertilizer price		-0.0541	0.0502	0.0450		
Pesticide price		-0.0550	0.0450	0.0102$^{\otimes}$		
Pig feed price			-0.0731	0.0517		
Cattle feed price				-0.0657		
Services price						0.0023$^{\otimes}$
Roughage price					0.0023$^{\otimes}$	
Activity levels (logs)						
Spring barley			0.0029			
Winter barley						
Wheat						
Pulses						
Rape					0.0005$^{\otimes}$	
Potatoes						
Sugar beets						
Dairy cows		0.0021*				0.0003*
Beef cattle						0.0009
Pigs				-0.0009*		-0.0001$^{\otimes}$
Poultry						
Fodder beets		0.0048	-0.0023		-0.0014*	-0.0002*
Grass in rotation						
Perm. grass	-0.0003*	0.0010$^{\otimes}$				
Fallow	-0.0004$^{\otimes}$	0.0020*		-0.0022		
Yield levels (logs)						
Spring barley				-0.0053		
Winter barley	-0.0022	0.0107			-0.0048	
Wheat			-0.0022*	0.0022		
Pulses	0.0009					
Rape						
Potatoes						0.0003*
Sugar beets	-0.0025		-0.0077			
Dairy cows					-0.0026	
Beef cattle	-0.0022	-0.0051*	-0.0035*			-0.0008*
Pigs	-0.0053	-0.0380		-0.0064	-0.0067$^{\otimes}$	
Poultry	0.0006$^{\otimes}$		0.0034			
Other variables						
Equipment (log)	0.0095	0.0136		0.0041*	-0.0386	
Buildings (log)				-0.0047		
Time-trend		-0.0057	-0.0023	0.0047	0.0024	
Standard Gross Margin (log)				0.0237	0.0382	-0.0037*
Crop share	0.0597	0.2165	0.3625	0.0841	0.1097	
Cattle share	0.0359*	0.1987	0.1899		0.0945	
Climate			0.0368			
Farmer's age	-0.0003				0.0005	
Effiency-proxy 1						0.0000
Effiency-proxy 2		0.0023*	-0.0015	0.0013		
Profitability		-0.0001$^{\otimes}$				
INVSDB		-1614.3829	-246.8954		377.3187	
INVSQSDB		42.9079		2.9454		-1.1416
Observations in the sample		42.9079		2.9454		1444
Cohorts in the sample						479

Note: Parameters with no indication is significant at the 1 percent level or below, * indicates significance at the 5 per cent-level and $^{\otimes}$ indicates significance at the 10 per cent level.

Table B.3. Cattle farms on loamy soil

Explanatory variables	Energy	Labour	Fertilizer	Pesticides	Services	Roughage
Price variables (logs)						
Energy price	-0.0177	-0.0165	0.0147			
Wage rate	-0.0165	0.1473	-0.0242	-0.0316		
Fertilizer price	0.0147	-0.0215	0.0157	0.0151		
Pesticide price		-0.0316	0.0151	0.0049 ⊗		0.0129
Pig feed price			-0.0198 ⊗			-0.0505*
Cattle feed price	-0.0198*			-0.0335		
Services price					0.0163*	
Roughage price				0.0129		-0.0213*
Activity levels (logs)						
Spring barley						
Winter barley						
Wheat						
Pulses						
Rape						
Potatoes						
Sugar beets						
Dairy cows					0.0087	0.0111
Beef cattle		-0.0042				
Pigs		-0.0032			-0.0011	-0.0007 ⊗
Poultry			-0.0004*			
Fodder beets		0.0021*	0.0006*	0.0006	0.0006*	-0.0029
Grass in rotation			0.0013			-0.0021*
Perm. grass		0.0010 ⊗	0.0004*			
Fallow						
Yield levels (logs)						
Spring barley		0.0037 ⊗				-0.0036*
Winter barley						-0.0028 ⊗
Wheat	-0.0005*	0.0024*			-0.0010	
Pulses		-0.0025*		0.0008		
Rape	0.0002 ⊗	-0.0018*	0.0006		0.0013	
Potatoes						
Sugar beets			-0.0021	0.0007		0.0044
Dairy cows	-0.0020	-0.0011	-0.0034	-0.0010 ⊗		
Beef cattle		0.0028 ⊗				
Pigs		-0.0070 ⊗				-0.0049*
Poultry	0.0003*			0.0007		
Other variables						
Equipment (log)	0.0051	-0.0273		0.0055	-0.0166	
Buildings (log)		-0.0268	0.0030 ⊗	-0.0031*		
Time-trend	-0.0003*	-0.0033*	-0.0011	0.0019	0.0023	0.0012*
Standard Gross Margin (log)		0.1759*			0.0119	
Crop share	-0.0156		0.0848 ⊗	0.0472		
Cattle share		-0.0702*				0.0341*
Climate	0.0084	-0.0383	0.0114			
Farmer's age		0.0020		-0.0002		
Effiency-proxy 1				0.0001*		0.0002 ⊗
Effiency-proxy 2	-0.0003 ⊗			-0.0005	-0.0009*	
Profitability	0.0000	-0.0001 ⊗		0.0001		
INVSDB		-4274.5519			248.4480*	509.8541 ⊗
INVSQSDB		121.8123	-3.004			-7.9130 ⊗
Observation in the sample						963
Cohorts in the sample						294

Note: Parameters with no indication is significant at the 1 percent level or below, * indicates significance at the 5 per cent-level and ⊗ indicates significance at the 10 per cent level.

Table B.4. Cattle farms on sandy soil

Explanatory variables	Energy	Labour	Fertilizer	Pesticides	Services	Roughage
Price variables (logs)						
Energy price	0.0154	-0.0160	0.0086	-0.0021		-0.0044
Wage rate	-0.0160	0.1766	-0.0429	-0.0239		
Fertilizer price	0.0086	-0.0429	0.0333	0.0060		0.0171
Pesticide price	-0.0021	-0.0239	0.0060	0.0042		0.0086
Pig feed price	-0.0091	-0.0671	-0.0178	-0.0112		
Cattle feed price	0.0062*					-0.0240
Services price					0.0165	
Roughage price	-0.0044		0.0171	0.0086		-0.0219
Activity levels (logs)						0.0302
Spring barley			0.0007		-0.0004	-0.0007*
Winter barley						
Wheat					-0.0005	
Pulses						
Rape						
Potatoes						0.0006
Sugar beets						0.0011
Dairy cows						
Beef cattle		-0.0020		-0.0003	-0.0011	0.0005
Pigs	-0.0002	-0.0023	-0.0019	-0.0002	-0.0004	
Poultry					-0.0007	
Fodder beets	0.0001	0.0018	0.0003	0.0012		-0.0013
Grass in rotation		0.0020	0.0014	-0.0002*		
Perm. grass	-0.0001	0.0007		-0.0001	-0.0003	
Fallow	-0.0003	0.0012	-0.0003⊗	-0.0005		0.0004*
Yield levels (logs)						
Spring barley		0.0043		0.0007		
Winter barley		0.0047				
Wheat				0.0013		
Pulses			-0.0003*	0.0008		
Rape		-0.0006⊗	0.0003*	0.0005		
Potatoes	0.0006	0.0020	0.0016		0.0013	
Sugar beets	-0.0008	-0.0031*	-0.0026			
Dairy cows	-0.0013⊗	-0.0077	-0.0055		-0.0013	
Beef cattle	-0.0002		-0.0005⊗	0.0006	0.0018	
Pigs	-0.0007	-0.0064	-0.0011⊗	-0.0007		
Poultry	-0.0001*				-0.0011	
Other variables						
Equipment (log)	0.0049	-0.0175	0.0049	0.0028	-0.0159	0.0011⊗
Buildings (log)	-0.0007*	-0.0377	-0.0058	-0.0009	0.0036	0.0023
Time-trend		-0.0030	-0.0011	0.0015	0.0019	0.0011
Standard Gross Margin (log)	-0.0053	0.0328	-0.0316	-0.0055*		
Crop share				0.0297	0.1105	
Cattle share	-0.0131	-0.1490	-0.0782	0.0106	0.0885	0.0327
Climate	0.0107	-0.0337	0.0202			
Farmer's age		0.0020	0.0001			-0.0003
Effiency-proxy 1	0.0000⊗					
Effiency-proxy 2		0.0023			-0.0010	-0.0007
Profitability	0.0000	-0.0002		0.0000	0.0001	
INVSDB	319.4113		465.8997	266.4765	-178.3641	-490.3818
INVSQSDB	-6.8574	19.7602	-20.5386	-6.3399		16.5687
Observations in the sample						7528
Cohort in the sample						1930

Note:. ⊗ indicates significance at the 10 per cent level, * indicates significance at the 5 per cent-level and parameters with no indication is significant at the 1 percent level or below.

Table B.5. Pig farms on loamy soil

Explanatory variables	Energy	Labour	Fertilizer	Pesticides	Services	Roughage
Price variables (logs)						
Energy price	0.0217					
Wage rate		0.1989	-0.0148	-0.0274		
Fertilizer price		-0.0148	0.0405			
Pesticide price		-0.0274		0.0086*		
Pig feed price			-0.0449	-0.0248		
Cattle feed price						
Services price					0.0312	
Roughage price						
Activity levels (logs)						
Spring barley						
Winter barley						
Wheat						
Pulses						
Rape					0.0003$^{\otimes}$	
Potatoes						
Sugar beets						-0.0002$^{\otimes}$
Dairy cows		0.0047			-0.0010*	0.0005*
Beef cattle						0.0006*
Pigs		0.0101$^{\otimes}$			0.0011*	
Poultry						
Fodder beets			-0.0021			-0.0006$^{\otimes}$
Grass in rotation						
Perm. grass					-0.0005*	0.0002$^{\otimes}$
Fallow	0.0003*			-0.0010		0.0004
Yield levels (logs)						
Spring barley			-0.0012$^{\otimes}$	0.0009$^{\otimes}$		
Winter barley			-0.0013*	-0.0015	-0.0011*	0.0005*
Wheat		-0.0060				
Pulses				0.0008		
Rape			0.0006			-0.0003
Potatoes						
Sugar beets			-0.0013			
Dairy cows					0.0023*	
Beef cattle						-0.0021
Pigs	-0.0105	-0.0942	-0.0239	-0.0149	-0.0097	
Poultry		0.0025*	0.0010*			
Other variables						
Equipment (log)	0.0024	-0.0242	-0.0058		-0.0083	
Buildings (log)	-0.0026	-0.0432	-0.0061	-0.0034	0.0033*	
Time-trend	-0.0011			0.0033		
Standard Gross Margin (log)		0.1018	0.0125			0.0103
Crop share	0.0269	0.3327	0.1555	0.0949	0.0250	
Cattle share		0.2242*	0.1039	0.0431		0.0401
Climate		-0.0382$^{\otimes}$	0.0268			
Farmer's age		0.0017		-0.0002*		
Effiency-proxy 1				-0.0001*		
Effiency-proxy 2	0.0005	0.0054		0.0005		
Profitability		-0.0002	0.0000$^{\otimes}$			
INVSDB	316.1011	-1498.6301*		277.0428		-240.7058
INVSQSDB	-7.2793	60.2725		-7.6870		6.6885
Observations in the sample						932
Cohorts in the sample						286

Note: Parameters with no indication are significant at the 1 percent level or below, * indicates significance at the 5 per cent-level and $^{\otimes}$ indicates significance at the 10 per cent level.

Table B.6. Pig farms on sandy soil

Explanatory variables	Energy	Labour	Fertilizer	Pesticides	Services	Roughage
Price variables (logs)						
Energy price	0.0254	-0.0070*	-0.0085			
Wage rate	-0.0070*	0.2069	-0.0144	-0.0144		
Fertilizer price	-0.0085	-0.0144	0.0340	0.0111		0.0041
Pesticide price		-0.0144	0.0111			
Pig feed price	-0.0142		-0.0214	-0.0083$^{\otimes}$	0.0182	0.0059*
Cattle feed price		-0.1581	-0.0285		-0.0328	-0.0045$^{\otimes}$
Services price					0.0270	
Roughage price			0.0041			
Activity levels (logs)						
Spring barley						
Winter barley						
Wheat						
Pulses						
Rape						
Potatoes						
Sugar beets						
Dairy cows					0.0005	0.0004
Beef cattle						
Pigs						
Poultry						
Fodder beets			0.0004$^{\otimes}$			-0.0002*
Grass in rotation						
Perm. grass		0.0008			0.0003*	
Fallow				-0.0007	-0.0003	0.0001$^{\otimes}$
Yield levels (logs)						
Spring barley		0.0029$^{\otimes}$				-0.0003$^{\otimes}$
Winter barley	0.0004*					
Wheat			-0.0010	0.0009		0.0002*
Pulses			-0.0004	0.0004	0.0002$^{\otimes}$	
Rape		-0.0018		0.0003	0.0005	
Potatoes	0.0003$^{\otimes}$			0.0004*	0.0010	0.0002*
Sugar beets			-0.0023	0.0015		
Dairy cows			-0.0009*			
Beef cattle						
Pigs	-0.0105	-0.1210	-0.0229	-0.0069	-0.0043*	
Poultry		0.0029				
Other variables						
Equipment (log)	0.0059	-0.0112			-0.0116	
Buildings (log)		-0.0146	-0.0023*		0.0024	
Time-trend	-0.0007	-0.0015$^{\otimes}$		0.0017		
Standard Gross Margin (log)			0.0034*	-0.0084	0.0195	
Crop share	0.0257	0.2685	0.1624	0.0620	0.0321	
Cattle share		0.1564	0.0729	0.0197	0.0189*	0.0192
Climate		-0.0407	0.0144	-0.0126	-0.0059$^{\otimes}$	
Farmer's age		0.0021		-0.0001*	0.0002	0.0000*
Effiency-proxy 1	0.0000		0.0000			
Effiency-proxy 2	-0.0002$^{\otimes}$	0.0015	-0.0003$^{\otimes}$	0.0002$^{\otimes}$		
Profitability	0.0000	-0.0001*	0.0000*			
INVSDB				418.7132	-695.3026	
INVSQSDB	-1.0331	14.9376	-140.2373	-10.8779	15.8697	
Observations in the sample						2011
Cohorts in the sample						622

Note: Parameters with no indication is significant at the 1 percent level or below, * indicates significance at the 5 per cent-level and $^{\otimes}$ indicates significance at the 10 per cent level.

Table B.7. Part time farms on loamy soil

Explanatory variables	Energy	Labour	Fertilizer	Pesticides	Services	Roughage
Price variables (logs)						
Energy price	0.0105*	-0.0329	0.0272			
Wage rate	-0.0329	0.1280	-0.0365	-0.0226		
Fertilizer price	0.0272	-0.0365	0.0196⊗	0.0129*		
Pesticide price		-0.0226	0.0129*			
Pig feed price						
Cattle feed price						
Services price					0.0185*	
Roughage price						0.0050*
Activity levels (logs)						
Spring barley						
Winter barley						
Wheat						
Pulses						
Rape						
Potatoes		-0.0109				
Sugar beets						
Dairy cows						
Beef cattle		0.0035	-0.0011*		-0.0021*	
Pigs		0.0031	-0.0029	-0.0008*	-0.0030	
Poultry				-0.0005*		
Fodder beets				0.0020		-0.0009
Grass in rotation			-0.0018*			
Perm. grass						
Fallow		0.0040*		-0.0025	-0.0035	
Yield levels (logs)						
Spring barley					-0.0033*	-0.0017
Winter barley						
Wheat				0.0016*		-0.0004*
Pulses			-0.0019	0.0015		
Rape		-0.0040	0.0011*		0.0018	
Potatoes			-0.0073⊗			
Sugar beets	-0.0005⊗	0.0076	-0.0055		-0.0038	0.00048*
Dairy cows		0.0040⊗		0.0015*		-0.0010
Beef cattle					0.0043*	
Pigs		-0.0191	-0.0085*			
Poultry			0.0020			
Other variables						
Equipment (log)	0.0066			0.0058	-0.0150	0.0008*
Buildings (log)						
Time-trend	0.0008*		-0.0027	0.0025		
Standard Gross Margin (log)	-0.0292*	-0.0380	0.0218	0.0189		
Crop share	0.0315	0.2871	0.2081	0.1043	0.0368	
Cattle share		0.2440	0.0550			0.0566
Climate			0.0358*	-0.0402		
Farmer's age	-0.0001⊗			-0.0004	0.0012	
Effiency-proxy 1						
Effiency-proxy 2						
Profitability		0.0001			-0.0001	
INVSDB	402.3812	215.2293*				
INVSQSDB	-14.2889					
Observations in the sample						913
Cohorts in the sample						318

Note: Parameters with no indication is significant at the 1 percent level or below, * indicates significance at the 5 per cent-level and ⊗ indicates significance at the 10 per cent level.

Table B.8. Part time farms on sandy soil

Explanatory variables	Energy	Labour	Fertilizer	Pesticides	Services	Roughage
Price variables (logs)						
Energy price	0.0223	-0.0225	0.0080⊗			
Wage rate	-0.0225	0.1665	-0.0772			
Fertilizer price	0.0080⊗	-0.0772	0.0544	0.0180		
Pesticide price			0.0180		-0.0156*	
Pig feed price			-0.0737	-0.0240⊗		
Cattle feed price						
Services price				-0.0156*		
Roughage price						
Activity levels (logs)						
Spring barley					-0.0019	
Winter barley						
Wheat						
Pulses						
Rape						
Potatoes						
Sugar beets						
Dairy cows	-0.0004⊗		-0.0015*			0.0005
Beef cattle	-0.0005*		-0.0014	-0.0011	0.0025	
Pigs	-0.0009	0.0023*	-0.0019	-0.0009	-0.0018	
Poultry						
Fodder beets		0.0036				-0.0005
Grass in rotation						-0.0003*
Perm. grass						-0.0003
Fallow		0.0036*	-0.0021*		-0.0027	
Yield levels (logs)						
Spring barley		0.0090	-0.0032*	0.0017⊗		
Winter barley					-0.0037⊗	
Wheat			-0.0031	0.0062	-0.0041	
Pulses			-0.0022	0.0014	0.0012*	-0.0003*
Rape		-0.0043	0.0008⊗	0.0010	0.0022	
Potatoes	0.0011*	0.0052	-0.0054	0.0011⊗		
Sugar beets			-0.0106			
Dairy cows			-0.0019⊗			-0.0021
Beef cattle					-0.0030⊗	
Pigs		-0.0129⊗	-0.0083*		-0.0112	
Poultry		-0.0032*	0.0028		0.0014⊗	
Other variables						
Equipment (log)	0.0040			0.0037	-0.0148	
Buildings (log)		-0.0146	0.0074	-0.0046	0.0075*	
Time-trend		-0.0031		0.0009	0.0022	0.0002*
Standard Gross Margin (log)		-0.1373	0.0170		-0.0107	0.0193
Crop share	0.0206	0.1916	0.2241	0.0546	0.0597	0.0034⊗
Cattle share		0.1457	0.0994	0.0308		0.0483
Climate		-0.0376				
Farmer's age	-0.0002	0.0014⊗		-0.0004	0.0006	-0.0001*
Effiency-proxy 1						
Effiency-proxy 2	-0.0006	0.0041	-0.0031		-0.0032	
Profitability					0.0001	0.0000*
INVSDB		807.9035		-58.4863		-100.5808*
INVSQSDB		-40.2070				5.8236
Observations in the sample						1410
Cohorts in the sample						522

Note: Parameters with no indication is significant at the 1 percent level or below, * indicates significance at the 5 per cent-level and ⊗ indicates significance at the 10 per cent level.

Appendix C. Estimated coefficients in yield equations (chapter 5).

Table C.1. Equation for spring barley yield

	Crops, loam	Crops, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Parttime, loam	Parttime, sand
Explanatory variables								
Prices (logs):								
Labour			0,0037	0,0043		0,0029		0,009
Fertiliser	0,0041				-0,0012			-0,0032
Pesticide		-0,0053		0,0007	0,0009			0,0017
Pig feed	-0,2372	-0,1649	-0,1701	-0,1720	-0,1354	-0,1062*	-0,9391	-0,6371
Cattle feed			0,2024	0,0795		-0,1776	0,4572*	
Poultry feed				0,0932		0,1595	0,4655**	0,8378
Services	-0,0024						-0,0033	
Roughage			-0,0036			-0,0003	-0,0017	
Activity levels (logs):								
Spring barley	0,3438	0,2928	0,1180	0,0565	0,0910	0,0826	0,2894	0,3001
Winter barley				-0,0016**				-0,0262
Wheat	-0,0142	-0,0089	-0,0021*	-0,0045	-0,0079	-0,0054	-0,0264	-0,0191
Pulses		-0,0094		-0,0047		-0,0051		-0,0147
Rape		-0,0044*	-0,0020*	-0,0037	-0,0042	-0,0025	-0,0206	-0,0201
Potatoes		-0,0096	-0,0134	-0,0084				
Sugar beets		-0,0251	-0,0064	-0,0043			-0,0267	-0,0514
Dairy cattle			-0,0799	-0,0140				-0,0130*
Beef cattle								-0,0126
Pigs			-0,0031*		0,0120**	-0,0495		-0,0215
Poultry					0,0025**			
Fodder beets		-0,0088*					0,0088*	
Grass in rotation			0,0039*		-0,0061*			
Perm. grass			0,0020*					
Fallow	0,0067*		-0,0042**	-0,0020				
Yield levels (logs):								
Spring barley	2,3314	2,4864	0,8078	0,7665	0,9262	0,9307	2,7073	2,7293
Other variables:								
Equipment (log)		-0,0878	-0,0351	-0,0108	-0,0891	-0,0285		
Buildings (log)	-0,0654			-0,0047**				-0,0302**
Trend			-0,0058	-0,0047		-0,0069	-0,0208	-0,0243
Economic size						0,0052		
Crop share	0,7126	0,6122	0,1141*	0,7469	0,4220	0,3888	0,9496	0,7208
Cattle share		0,3355*		0,1300				
Climate	-0,2140	-0,1325*			-0,1257		-0,1940**	-0,3083
Farmer's age								
Efficiency proxy 1								
Efficiency proxy 2			0,0005*					
Profitability			0,0003	0,0002			0,0005**	0,0005*
INVSDB	4677,39							
INVSQSDB								

Table C.2. Equation for winter barley yield

	Crops, loam	Crops, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Part-time, loam	Part-time, sand
Explanatory variables								
Activity levels (logs):								
Winter barley	0,1168	0,1369		0,0425	0,0625			
Sugar beets	-0,1058*							
Pigs	-0,0383				-0,0581			
Yield levels (logs):								
Winter barley	0,0484	0,0507		0,0048	0,0965			
Other variables:								
Cattle share					3,9250*			
Efficiency proxy 2	-0,0118*							
Profitability	0,0002*							

Table C.3. Equation for wheat yield

	Crops, loam	Crops, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Part-time, loam	Part-time, sand
Explanatory variables								
Prices (logs):								
Energy			-0,0005					
Labour			0,0024		-0,006			
Fertiliser		-0,0022				-0,001		-0,0031
Pesticide	0,002	0,0022		0,0013		0,0009	0,0016	0,0062
Pig feed	-0,2092*	-0,4392						
Cattle feed	-0,2585							
Poultry feed	0,4562	0,5670	0,0579*					
Services	-0,0022		-0,0010					-0,0041
Roughage						0,0002	-0,0004	
Activity levels (logs):								
Spring barley		-0,0103		-0,0021		-0,0017**	-0,0214	-0,0175
Winter barley				-0,0012*				
Wheat	0,3151	0,2312	0,0914	0,0431	0,1114	0,0848	0,3580	0,2814
Pulses							-0,0143*	
Rape				-0,0010			-0,0112	
Sugar beets			-0,0047*					
Dairy cattle					0,0050**			-0,0354
Beef cattle	-0,0062*			-0,0038				
Pigs	-0,0076					-0,0518	-0,0168*	
Poultry								
Grass in rotation								0,0164*
Perm. grass	-0,0053							
Fallow		0,0044**						
Yield levels (logs):								
Wheat	1,8087	0,5362	0,1884	0,0463	0,6251	0,2248	1,0385	0,4003
Other variables:								
Equipment (log)	0,0339						-0,1251	
Buildings (log)					-0,0368			
Trend	-0,0208	-0,0131*	-0,0104	-0,0034		-0,0084	-0,0245	
Economic size	-0,4503	-0,8436*					-2,2989	
Crop share	0,5526			0,2778	0,2395			
Cattle share				0,1692		-0,2475		
Farmer's age	-0,0019**		0,0023					
Efficiency proxy 1	-0,0069	-0,0149						
Efficiency proxy 2								
Profitability	0,0005							0,0007
INVSDB	11094,6**	34344,9**					19012,9	
INVSQSDB	-218,66*	-652,26*					-891,421	

Table C.4. Equation for yield in pulses								
	Crops, loam	Crops, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Parttime, loam	Parttime, sand
Explanatory variables								
Prices (logs):								
Energy		0,0009						
Labour								
Fertiliser				-0,0003		-0,0004	-0,0019	-0,0022
Pesticide	0,001			0,0008	0,0008	0,0004	0,0015	0,0014
Pig feed				0,0872		0,0314*		
Cattle feed	-0,5148			-0,2115	-0,2154	-0,0908		
Poultry feed	0,6426				0,2473			
Services	-0,0009					0,0002		0,0012
Roughage								-0,0003
Activity levels (log):								
Spring barley								
Wheat		-0,0051						
Pulses	0,0838	0,1316		0,0408	0,0344	0,0337	0,1604	0,1762
Rape	0,0034*			-0,0004**				-0,0053
Potatoes		-0,0058**						
Dairy cattle				-0,0172				-0,0181
Pigs	-0,0068	-0,0045*				-0,0262		
Poultry								
Perm. grass		0,0046*						
Fallow								
Yield levels (logs):								
Pulses	0,2088	0,3230	0,0120	0,0420	0,0778	0,1136	0,0778	0,2266
Other variables:								
Equipment (log)								
Buildings (log)		-0,0589		-0,0123				
Trend	-0,0144	-0,0180		-0,0116		-0,0076		-0,0306
Crop share				0,0418*	0,1449			
Cattle share		-0,4743				0,0492*		
Climate		0,2431		0,0940				
Efficiency proxy 1								
Efficiency proxy 2						0,00003		
Profitability		-0,0004		0,0001	0,0001*			

Table C.5. Equation for rape yield

	Crops, loam	Crops, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Part-time, loam	Part-time, sand
Explanatory variables								
Prices (logs):								
Energy			0,0002					
Labour			-0,0018	-0,0006		-0,0018	-0,004	-0,0043
Fertiliser	0,0012		0,0006	0,0003	0,0006		0,0011	0,0008
Pesticide	-0,0006			0,0005		0,0003		0,001
Pig feed	0,1668*							
Cattle feed	-0,2037*				0,0893*	0,0862		
Poultry feed					-0,1285	-0,0760		
Services	0,0007		0,0013			0,0005	0,0018	0,0022
Roughage	-0,0001				-0,0003			
Activity levels (logs):								
Spring barley							0,0075**	
Winter barley		-0,0042**						
Wheat		-0,0027**			-0,0017			
Rape	0,1553	0,1348	0,0541	0,0337	0,0572	0,0419	0,2102	0,1994
Potatoes	-0,0172			-0,0024				
Dairy cattle								
Beef cattle								
Pigs						-0,0379		
Poultry		-0,0058*					-0,0062*	-0,0060
Grass in rotation								
Perm. grass	-0,0045*							
Fallow								
Yield levels (logs):								
Rape	0,3280	0,3099	0,0270	0,0231	0,1941	0,1300	0,3133	0,2577
Other variables:								
Equipment (log)		-0,0339*			-0,0396		-0,1102	0,0198*
Buildings (log)								-0,0176*
Trend						-0,0019	-0,0184	
Economic size	-0,2671							-0,9124*
Crop share	0,2562			0,1302				
Cattle share						-0,1298		
Climate	-0,2205	-0,1187		-0,0593	-0,0335*	-0,0458	-0,2396	-0,1917
Efficiency proxy 1				0,0034		0,0005**		-0,0178
Efficiency proxy 2						0,00004		
Profitability							0,0004	0,0008
INVSDB								13691,9*
INVSQSDB	-77,272							-412,73*

Table C.6. Equation for potato yield

	Crops, loam	Crops, sand	Crops, loam	Cattle, sand	Pigs, loam	Pigs, sand	Part-time, loam	Part-time, sand
Explanatory variables								
Prices (logs):								
Energy				0,0006				
Labour				0,002				
Fertiliser				0,0016				
Pesticide								
Pig feed		0,5876				0,0926		
Cattle feed		-0,3608						
Poultry feed		-0,3741*						
Services				0,0013				
Roughage		0,0003						
Activity levels (logs):								
Winter barley		-0,0128*						
Rape		-0,0061*						
Potatoes		0,2879		0,0819		0,0478		
Dairy cattle								
Fallow								
Yield levels (logs):								
Potatoes		0,4464						
Other variables:								
Economic size								
Crop share		0,8483						
Cattle share		0,6292						
Profitability		0,0005						
INVSQSDB		-44,409*						

Table C.7. Equation for sugarbeet yield

	Crops, loam	Crops, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Part-time, loam	Part-time, sand
Explanatory variables								
Prices (logs):								
Energy	-0,0011							
Labour								
Fertiliser	-0,0029		-0,0021		-0,0013			
Pesticide	0,0015		0,0007					
Pig feed	-0,0516				-0,0818			
Cattle feed	-0,4299							
Poultry feed	0,6409							
Services								
Roughage	-0,0020		0,0044					
Activity levels (log):								
Rape								
Sugar beets	0,3719	0,2172	0,1410		0,0966		0,2998	
Dairy cattle			-0,0526					
Beef cattle	-0,0119							
Pigs	-0,0110				-0,0402			
Poultry	-0,0073				-0,0035			
Perm. grass	-0,0077				0,0024**			
Fallow	0,0104				0,0038			
Yield levels (logs):								
Sugar beets	0,8929						0,2232	
Other variables:								
Equipment (log)								
Trend	0,0095*							
Farmer's age	-0,0045							
Efficiency proxy 1					0,0021*			
Efficiency proxy 2					0,0011			
Profitability	0,0004							
INVSDB	-17225,6							
INVSQSDB	299,588							

Table C.8. Equation for milk yield per dairy cow

	Crops, loam	Crops, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Part-time, loam	Part-time, sand
Explanatory variables								
Prices (logs):								
Energy			-0,002	-0,0013				
Labour	0,0095		-0,0011	-0,0077			0,004	
Fertiliser			-0,0034	-0,0055		-0,0009		-0,0019
Pesticide			-0,001				0,0015	
Pig feed			0,3005	0,1936				
Cattle feed			-0,3062	-0,3248				
Poultry feed			-0,1926	-0,0798				
Services		-0,0026		-0,0013	0,0023			
Roughage	0,0008						-0,001	-0,0021
Activity levels (logs):								
Spring barley			0,0032**	0,0027				
Rape	0,0134*							
Potatoes				-0,0039				
Sugar beets			-0,0044*	-0,0111				
Dairy cattle	0,2358	0,1939	0,1976	0,1689				0,1340
Beef cattle				-0,0120				
Pigs				-0,0050		-0,2443		0,0107
Poultry	-0,0183			0,0012				
Perm. grass			0,0039	-0,0012				
Fallow								
Yield levels (logs):								
Dairy cattle	20,0196	12,0119	640,2304	593,2414	2,0020	13,0128	16,0157	42,0402
Other variables:								
Equipment (log)			-0,0304*					
Buildings (log)				-0,0177				
Trend				0,0055				
Economic size	-1,1859*			-0,2432				
Crop share			0,5100	0,5122				
Cattle share			0,8227	0,8409				
Climate			-0,1109	-0,0470				
Farmer's age			0,0022*					
Efficiency proxy 1			0,0060	0,0082				
Profitability			0,0012	0,0012				
INVSDB				3285,703				2557,01**
INVSQSDB	-383,190*			-122,030				-790,388*

Table C.9. Equation for yield per beef cattle unit

	Crops, loam	Crops, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Parttime, loam	Parttime, sand
Explanatory variables								
Prices (logs):								
Energy		-0,0022		-0,0002				
Labour		-0,0051	0,0028					
Fertiliser		-0,0035		-0,0005				
Pesticide	-0,0055			0,0006				
Pig feed		0,4328	0,1552	0,1371				0,3352
Cattle feed		-0,6257		-0,0920				-0,2175*
Poultry feed			-0,1711	-0,1374				-0,2521*
Services				0,0018			0,0043	-0,0030
Roughage	0,001	-0,0008			-0,0021			
Activity levels (logs):								
Spring barley			-0,0029*					
Wheat				-0,0007**				
Pulses	0,0042**							
Potatoes								
Sugar beets							-0,0256	-0,0339*
Dairy cattle	0,0065		-0,1854	-0,0428				
Beef cattle	0,0611	0,0711	0,1131	0,2044	0,0109*	0,0306	0,1038	0,1263
Pigs				-0,0009				-0,0156
Poultry				0,0004**				
Fodder beets				-0,0009**			-0,0077*	
Grass in rotation				-0,0013*				
Perm. grass								
Fallow		-0,0075*		-0,0016				
Yield levels (logs):								
Beef cattle	33,0319	68,0634	188,1527	290,2059	5,0050	13,0128	30,0291	51,0484
Other variables:								
Equipment (log)		-0,0640		-0,0174			-0,0813	
Buildings (log)	0,0299**			-0,0122				
Trend			-0,0141			-0,0074		
Economic size				-0,1783				
Crop share				0,2825				
Cattle share		0,3408	0,0703*	0,2273	0,3926			
Climate				-0,0376				
Farmer's age	-0,0100		0,0022*	0,0004		0,0035		
Efficiency proxy 1		0,0165	0,0053	0,0015				0,0205
Efficiency proxy 2						0,0002*	0,0133	
Profitability	0,0004		0,0004	0,0003				-0,0008
INVSDB			-1897,65					
INVSQSDB				-34,2188				

Table C.10. Equation for yield per pig unit

	Crops, loam	Crops, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Part-time, loam	Part-time, sand
Explanatory variables								
Prices (logs):								
Energy		-0,0053		-0,0007	-0,0105	-0,0105		
Labour	-0,0258	-0,038	-0,007	-0,0064	-0,0942	-0,121	-0,0191	-0,0129
Fertiliser				-0,0011	-0,0239	-0,0229	-0,0085	-0,0083
Pesticide	-0,0094	-0,0064		-0,0007	-0,0149	-0,0069		
Pig feed	0,5039	0,3498			1,0294	0,8443		0,4375
Cattle feed			0,0803**				0,3662	
Poultry feed	-0,7088	-0,4465	-0,1191		-1,4622	-1,1628	-0,2798	-0,6448
Services		-0,0067			-0,0097	-0,0043		-0,0112
Roughage	-0,0009		-0,0049					
Activity levels (logs):								
Spring barley				-0,0025*				
Wheat	-0,0046*	-0,0051*				-0,0026**		
Pulses							-0,0092**	
Rape			-0,0068	-0,0016*				-0,0054*
Potatoes				-0,0038				
Sugar beets			-0,0062	-0,0110			0,0165**	-0,0326
Dairy cattle		0,0089*	-0,0563	-0,0181				-0,0108
Beef cattle				-0,0033				-0,0132
Pigs	0,1040	0,1152	0,0787	0,0471	0,1395	0,2310	0,1245	0,1305
Poultry		-0,0112		-0,0011				
Fodder beets				-0,0039				-0,0085*
Grass in rotation								
Perm. grass	-0,0099						0,0066**	-0,0081
Fallow						-0,0047*		
Yield levels (logs):								
Pigs	44,0421	57,0538	18,0177	20,0196	243,1840	273,1985	57,0538	46,0439
Other variables:								
Equipment (log)		-0,0766		-0,0091		-0,0732	-0,0419**	
Buildings (log)								
Trend	-0,0145		-0,0055*	-0,0052	-0,0184	-0,0165	-0,0249	-0,0143
Economic size	0,2691				-0,2152*			
Crop share	-1,0317	-0,9800	-0,2739*	-0,7251	-0,6257		-0,5436	-0,4677
Cattle share	-1,6615	-1,6092	-0,2526*	-0,9402		-0,9557	-1,0671	-0,5584
Climate		-0,2776			-0,3013	-0,3369	-0,2206	
Farmer's age					0,0047*			
Efficiency proxy 1	0,0240	0,0152	0,0034*	0,0040	0,0224	0,0172		0,0172
Efficiency proxy 2	0,0003*		-0,0012*					
Profitability				0,0004	0,0004	0,0002*	0,0010	
INVSQSDB	73,1174*				-71,991*			

Table C.11. Equation for yield per poultry unit

	Crops, loam	Crops, sand	Cattle, loam	Cattle, sand	Pigs, loam	Pigs, sand	Part-time, loam	Part-time, sand
Explanatory variables								
Prices (logs):								
Energy		0,0006	0,0003	-0,0001				
Labour	-0,0195				0,0025	0,0029		-0,0032
Fertiliser		0,0034			0,001		0,002	0,0028
Pesticide			0,0007					
Cattle feed			-0,0178	-0,0176				
Poultry feed				0,0123*				
Services				-0,0011				0,0014
Roughage	0,0004							
Activity levels (logs):								
Spring barley		0,0096						
Winter barley					0,7817			
Rape				-0,0005*				
Potatoes				-0,0013				
Sugar beets			-0,0011*	0,0180				
Dairy cattle				0,0053				
Beef cattle								-0,0015
Pigs				-0,0009		-0,0354*		
Poultry	0,0177	0,0302	0,0150	0,0156	0,0571		0,0196	0,0105
Fodder beets								
Grass in rotation								
Perm. grass								
Fallow	-0,0039			-0,0009*				
Yield levels (logs):								
Poultry	12,0119	15,0148	9,0089	3,0030	23,0225	11,0109	16,0157	8,0079
Other variables:								
Equipment (log)	-0,0159*							
Trend		0,0239						
Economic size		0,9114		0,1419				
Crop share	0,0858*							
Cattle share				-0,0358				
Climate					-0,1107*			
Farmer's age		-0,0232						
Efficiency proxy 1								
Efficiency proxy 2							0,0003	
Profitability		0,0002*						
INVSDB		-18245,7		-2590,76				
INVSQSDB		534,335		81,0416				

Appendix D. Output-compensated price elasticities of input demand

Table D.12. Hicksian input price elasticities for crop farms on loamy soil

	Energy	Labour	Fertilisers	Pesti-cides	Services	Rough-age	Conc. feed
Energy price	-0,298	-0,014	0,127	-0,031	0,055	0,055	0,018
	0,191	0,018	0,031	0,043	0,015	0,015	0,000
Wage rate	-0,126	0,019	0,207	-0,276	0,507	0,507	-0,264
	0,189	0,091	0,099	0,255	0,058	0,058	0,000
Fertiliser price	0,394	0,069	-0,583	0,466	0,170	3,070	-0,132
	0,101	0,040	0,078	0,109	0,034	8,031	0,000
Pesticide price	0,251	-0,053	0,269	-0,902	0,098	1,498	0,388
	0,075	0,037	0,054	0,030	0,030	3,922	0,000
Service price	0,042	0,042	0,042	0,042	0,259	-7,658	-0,241
	0,024	0,024	0,024	0,024	0,715	21,228	0,000
Roughage price	0,002	0,002	0,036	0,031	-0,365	-0,998	-0,944
	0,006	0,006	0,014	0,018	0,222	1,000	0,000
Cattle feed price	0,034	0,034	0,034	0,034	0,034	-5,416	0,121
	0,003	0,003	0,003	0,003	0,003	15,107	0,000
Pig feed price	0,089	0,262	0,089	0,089	0,089	0,089	-0,606
	0,005	0,058	0,005	0,005	0,005	0,005	0,000
Chicken feed price	-0,388	-0,362	-0,221	0,547	-0,847	8,853	1,661
	0,167	0,082	0,094	0,191	0,517	24,508	0,000

Note: Standard deviations in small font.

Table D.2. Hicksian input price elasticities for crop farms on sandy soil

	Energy	Labour	Fertilisers	Pesti-cides	Services	Rough-age	Conc. feed
Energy price	-0,150	-0,012	0,055	0,055	0,055	0,055	-0,013
	0,237	0,019	0,016	0,016	0,016	0,016	0,000
Wage rate	-0,108	-0,156	0,210	-0,526	0,512	0,512	0,325
	0,198	0,080	0,106	0,530	0,059	0,059	0,000
Fertiliser price	0,179	0,073	-0,541	1,028	0,179	0,179	-0,110
	0,040	0,046	0,092	0,434	0,040	0,040	0,000
Pesticide price	0,053	-0,054	0,304	-0,755	0,053	0,053	0,052
	0,026	0,032	0,071	0,141	0,026	0,026	0,000
Service price	0,056	0,056	0,056	0,056	-0,944	0,823	0,040
	0,035	0,035	0,035	0,035	0,035	1,900	0,000
Roughage price	0,003	0,003	0,003	0,003	0,044	-0,997	-1,013
	0,007	0,007	0,007	0,007	0,037	0,007	0,000
Cattle feed price	0,054	0,054	0,054	-1,185	0,054	0,054	0,517
	0,004	0,004	0,004	0,722	0,004	0,004	0,000
Pig feed price	0,082	0,082	-0,326	1,057	0,082	0,082	0,233
	0,005	0,005	0,152	0,589	0,005	0,005	0,000
Chicken feed price	-0,169	-0,046	0,185	0,266	-0,035	-0,761	-0,029
	0,101	0,047	0,154	0,572	0,036	1,899	0,000

Note: Standard deviations in small font.

Table D.3. Hicksian input price elasticities for cattle farms on loamy soil

	Energy	Labour	Fertilisers	Pesti-cides	Services	Rough-age	Conc. feed
Energy price	-1,560	-0,004	0,330	0,030	0,030	0,030	0,089
	0,146	0,008	0,198	0,006	0,006	0,006	0,000
Wage rate	-0,062	-0,210	-0,006	-1,092	0,488	0,488	0,263
	0,136	0,061	0,337	0,783	0,039	0,259	0,000
Fertiliser price	0,539	0,005	-0,631	0,804	0,049	0,049	-0,023
	0,134	0,033	0,224	0,384	0,031	0,031	0,000
Pesticide price	0,020	-0,045	0,328	-0,735	0,020	0,378	0,016
	0,010	0,014	0,205	1,255	0,010	0,269	0,000
Service price	0,044	0,044	0,044	0,044	-0,586	0,044	-0,005
	0,016	0,016	0,016	0,016	0,432	0,016	0,000
Roughage price	0,036	0,036	0,036	0,681	0,036	-1,556	-0,939
	0,025	0,031	0,025	0,359	0,025	0,412	0,000
Cattle feed price	-0,393	0,267	0,267	-1,408	0,267	0,267	0,427
	0,215	0,022	0,022	0,878	0,022	0,022	0,000
Pig feed price	0,062	0,062	-0,342	0,062	0,062	-1,341	0,273
	0,011	0,011	0,259	0,011	0,011	1,091	0,000
Chicken feed price	1,314	-0,155	-0,027	1,614	-0,367	1,640	-0,101
	0,344	0,048	0,158	1,544	0,432	1,268	0,000

Note: Standard deviations in small font.

Table D.4. Hicksian input price elasticities for cattle farms on sandy soil

	Energy	Labour	Fertilisers	Pesti-cides	Services	Rough-age	Conc. feed
Energy price	-0,457	-0,004	0,151	-0,101	0,030	-0,214	0,026
	0,130	0,009	0,037	0,082	0,007	0,280	0,000
Wage rate	-0,059	-0,153	-0,130	-1,020	0,474	0,474	0,199
	0,145	0,064	0,174	0,791	0,049	0,049	0,000
Fertiliser price	0,358	-0,020	-0,464	0,446	0,071	1,021	0,007
	0,083	0,022	0,130	0,206	0,019	1,067	0,000
Pesticide price	-0,054	-0,034	0,101	-0,722	0,016	0,494	0,037
	0,030	0,010	0,027	0,147	0,008	0,538	0,000
Service price	0,050	0,050	0,050	0,050	-0,620	0,050	0,002
	0,019	0,019	0,019	0,019	0,138	0,019	0,000
Roughage price	-0,129	0,018	0,259	0,556	0,018	-2,199	-0,980
	0,055	0,020	0,074	0,293	0,020	1,365	0,000
Cattle feed price	0,489	0,282	0,282	0,282	0,282	-1,051	0,335
	0,108	0,018	0,018	0,018	0,018	1,521	0,000
Pig feed price	-0,246	-0,084	-0,193	-0,642	0,058	0,058	0,366
	0,115	0,032	0,097	0,390	0,008	0,008	0,000
Chicken feed price	0,048	-0,055	-0,055	1,151	-0,329	1,368	0,009
	0,149	0,032	0,093	0,635	0,136	1,570	0,000

Note: Standard deviations in small font.

Table D.5. Hicksian input price elasticities for pig farms on loamy soil

	Energy	Labour	Fertilisers	Pesti-cides	Services	Rough-age	Conc. feed
Energy price	-0,361	0,036	0,036	0,036	0,036	0,036	-0,006
	0,158	0,008	0,079	0,075	0,008	0,008	0,000
Wage rate	0,346	-0,079	0,024	-0,510	0,346	0,346	0,041
	0,050	0,109	1,072	0,401	0,050	0,050	0,000
Fertiliser price	0,046	0,003	-0,074	0,046	0,046	0,046	-0,004
	0,101	0,022	0,335	0,120	0,016	0,016	0,000
Pesticide price	0,032	-0,047	0,032	-0,699	0,032	0,032	0,069
	0,068	0,025	0,084	0,169	0,013	0,013	0,000
Service price	0,025	0,025	0,025	0,025	0,273	0,025	-0,036
	0,014	0,014	0,014	0,014	0,735	0,014	0,000
Roughage price	0,002	0,002	0,002	0,002	0,002	-0,998	-0,998
	0,007	0,007	0,007	0,007	0,007	0,007	0,000
Cattle feed price	0,004	0,004	0,004	0,004	0,004	0,004	0,004
	0,289	0,001	0,302	0,001	0,001	0,001	0,000
Pig feed price	0,498	0,498	-0,478	-0,277	0,498	0,498	0,634
	0,217	0,007	0,337	0,429	0,404	0,007	0,000
Chicken feed price	-0,592	-0,442	0,428	1,374	-1,237	0,011	0,297
	0,412	0,086	1,131	0,682	0,839	0,001	0,000

Note: Standard deviations in small font.

Table D.6. Hicksian input price elasticities for pig farms on sandy soil

	Energy	Labour	Fertilisers	Pesti-cides	Services	Rough-age	Conc. feed
Energy price	-0,239	0,014	-0,167	0,035	0,035	0,035	0,017
	0,184	0,012	0,078	0,008	0,008	0,008	0,000
Wage rate	0,138	-0,050	-0,005	-0,382	0,338	0,338	0,020
	0,105	0,098	0,128	0,342	0,042	0,042	0,000
Fertiliser price	-0,201	-0,001	-0,148	0,597	0,042	2,092	-0,007
	0,087	0,016	0,252	0,259	0,012	4,774	0,000
Pesticide price	0,020	-0,023	0,284	-0,980	0,020	0,020	0,026
	0,009	0,013	0,089	0,009	0,009	0,009	0,000
Service price	0,025	0,025	0,025	0,025	0,105	0,025	-0,025
	0,011	0,011	0,011	0,011	0,500	0,011	0,000
Roughage price	0,002	0,002	0,100	0,002	0,002	-0,998	-1,006
	0,005	0,005	0,045	0,005	0,005	0,600	0,000
Cattle feed price	0,015	-0,452	-0,663	0,015	-1,297	-2,235	0,432
	0,001	0,097	0,309	0,001	0,659	5,432	0,000
Pig feed price	0,112	0,518	0,009	0,118	1,246	3,468	0,554
	0,152	0,005	0,240	0,275	0,422	6,918	0,000
Chicken feed price	0,127	-0,034	0,566	0,570	-0,491	-2,745	-0,011
	0,170	0,090	0,380	0,367	0,487	6,743	0,000

Note: Standard deviations in small font.

Table D.7. Hicksian input price elasticities for part-time farms on loamy soil

	Energy	Labour	Fertilisers	Pesti-cides	Services	Rough-age	Conc. feed
Energy price	-0,686	-0,021	0,263	0,038	0,038	0,038	0,008
	0,176	0,020	0,077	0,015	0,015	0,015	0,000
Wage rate	-0,313	-0,216	0,251	0,082	0,553	0,553	0,329
	0,383	0,078	0,145	0,301	0,066	0,066	0,000
Fertiliser price	0,837	0,055	-0,717	0,390	0,121	0,121	-0,023
	0,317	0,041	0,108	0,189	0,034	0,034	0,000
Pesticide price	0,048	0,007	0,155	-0,952	0,048	0,048	0,108
	0,024	0,029	0,064	0,024	0,024	0,024	0,000
Service price	0,075	0,075	0,075	0,075	-0,678	0,075	-0,040
	0,033	0,033	0,033	0,033	0,158	0,033	0,000
Roughage price	0,004	0,004	0,004	0,004	0,004	0,254	-1,027
	0,007	0,007	0,007	0,007	0,007	2,153	0,000
Cattle feed price	0,038	0,038	0,038	0,038	0,038	0,038	0,038
	0,003	0,003	0,003	0,003	0,003	0,003	0,000
Pig feed price	0,120	0,120	0,120	0,120	0,120	0,120	0,120
	0,006	0,006	0,006	0,006	0,006	0,006	0,000
Chicken feed price	-0,123	-0,062	-0,189	0,205	-0,244	-1,247	0,486
	0,253	0,043	0,159	0,240	0,155	2,153	0,000

Note: Standard deviations in small font.

Table D.8. Hicksian input price elasticities for part-time farms on sandy soil

	Energy	Labour	Fertilisers	Pesti-cides	Services	Rough-age	Conc. feed
Energy price	-0,389	-0,003	0,101	0,039	0,039	0,039	-0,007
	0,277	0,019	0,046	0,017	0,017	0,017	0,000
Wage rate	-0,037	-0,152	-0,058	0,540	0,540	0,540	0,147
	0,275	0,093	0,202	0,073	0,073	0,073	0,000
Fertiliser price	0,334	-0,014	-0,449	0,692	0,129	0,129	0,110
	0,160	0,045	0,155	0,515	0,038	0,038	0,000
Pesticide price	0,032	0,032	0,172	-0,968	-0,152	0,032	0,018
	0,027	0,027	0,066	0,027	0,126	0,027	0,000
Service price	0,085	0,085	0,085	-0,403	-0,915	0,085	0,177
	0,044	0,044	0,044	0,468	0,044	0,044	0,000
Roughage price	0,005	0,005	0,005	0,005	0,005	-0,995	-0,995
	0,009	0,009	0,009	0,009	0,009	0,009	0,000
Cattle feed price	0,066	0,066	0,066	0,066	0,066	0,066	0,066
	0,005	0,005	0,005	0,005	0,005	0,005	0,000
Pig feed price	0,103	0,103	-0,468	-0,647	0,103	0,103	0,678
	0,007	0,007	0,230	0,782	0,007	0,007	0,000
Chicken feed price	-0,199	-0,123	0,547	0,676	0,184	0,001	-0,194
	0,202	0,046	0,255	0,780	0,123	0,001	0,000

Note: Standard deviations in small font.

Appendix E. Estimated yield response parameters to price changes for eight farm types

Table E.1. Yield elasticities, crop farms on loamy soil

	Output price	Energy price	Wage rate	Fertiliser price	Pesticide price	Services price	Rough-age price	Concen-trate feed price
Spring barley	0,255	-0,014	-0,129	-0,045	-0,025	-0,010	-0,001	-0,031
Winter barley	0,260	-0,014	-0,132	-0,044	-0,025	-0,011	-0,001	-0,033
Wheat	0,275	-0,015	-0,139	-0,047	-0,028	-0,010	-0,001	-0,035
Pulses	0,200	-0,011	-0,101	-0,034	-0,025	-0,003	0,000	-0,025
Rape	0,350	-0,019	-0,177	-0,064	-0,032	-0,017	0,000	-0,040
Potatoes	0,005	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Sugar beets	0,005	0,001	-0,002	-0,009	-0,002	0,000	0,002	0,006
Dairy cattle	0,001	0,000	-0,001	0,000	0,000	0,000	0,000	0,000
Beef cattle	0,001	0,000	-0,001	0,000	0,000	0,000	0,000	0,000
Pigs	0,001	0,000	0,000	0,000	0,000	0,000	0,000	-0,001
Poultry	0,001	0,000	0,001	0,000	0,000	0,000	0,000	-0,002

Table E.2. Yield elasticities, crop farms on sandy soil

	Output price	Energy price	Wage rate	Fertiliser price	Pesticide price	Services price	Rough-age price	Concen-trate feed price
Spring barley	0,250	-0,014	-0,128	-0,045	-0,011	-0,014	-0,001	-0,038
Winter barley	0,245	0,040	-0,388	-0,044	-0,013	0,104	-0,001	0,056
Wheat	0,290	-0,016	-0,148	-0,047	-0,021	-0,016	-0,001	-0,041
Pulses	0,190	-0,014	-0,097	-0,034	-0,010	-0,011	-0,001	-0,024
Rape	0,355	-0,020	-0,182	-0,064	-0,019	-0,020	-0,001	-0,050
Potatoes	0,005	0,000	-0,002	-0,001	0,000	0,000	-0,001	0,000
Sugar beets	0,005	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Dairy cattle	0,001	0,000	-0,001	0,000	0,000	0,000	0,000	0,000
Beef cattle	0,001	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Pigs	0,001	0,000	0,000	0,000	0,000	0,000	0,000	-0,001
Poultry	0,001	0,000	-0,001	0,000	0,000	0,000	0,000	0,000

Table E.3. Yield elasticities, cattle farms on loamy soil

	Output price	Energy price	Wage rate	Fertiliser price	Pesticide price	Services price	Rough-age price	Concen-trate feed price
Spring barley	0,255	-0,008	-0,130	-0,012	-0,005	-0,011	-0,004	-0,085
Winter barley	0,260	-0,008	-0,127	-0,013	-0,005	-0,011	0,173	-0,269
Wheat	0,275	-0,005	-0,150	-0,013	-0,006	-0,005	-0,010	-0,086
Pulses	0,200	-0,006	0,152	-0,010	-0,084	-0,009	-0,007	-0,237
Rape	0,350	-0,021	-0,081	-0,047	-0,007	-0,080	-0,013	-0,102
Potatoes	0,005	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Sugar beets	0,005	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Dairy cattle	0,001	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Beef cattle	0,001	0,000	-0,001	0,000	0,000	0,000	0,000	0,000
Pigs	0,001	0,000	0,000	0,000	0,000	0,000	0,000	-0,002
Poultry	0,001	0,000	0,000	0,000	0,000	0,000	0,000	0,000

Table E.4. Yield elasticities, cattle farms on sandy soil

	Output price	Energy price	Wage rate	Fertiliser price	Pesticide price	Services price	Rough-age price	Concen-trate feed price
Spring barley	0,255	-0,008	-0,128	-0,018	-0,005	-0,013	-0,005	-0,079
Winter barley	0,260	-0,008	-1,345	-0,018	-0,004	-0,013	-0,005	1,133
Wheat	0,275	-0,008	-0,130	-0,020	-0,040	-0,014	-0,005	-0,058
Pulses	0,200	-0,006	-0,095	-0,006	-0,026	-0,010	-0,004	-0,054
Rape	0,350	-0,011	-0,131	-0,042	-0,035	-0,018	-0,006	-0,108
Potatoes	0,005	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Sugar beets	0,005	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Dairy cattle	0,001	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Beef cattle	0,001	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Pigs	0,001	0,000	0,000	0,000	0,000	0,000	0,000	-0,001
Poultry	0,001	0,000	0,000	0,000	0,000	0,000	0,000	-0,001

Table E.5. Yield elasticities, pig farms on loamy soil

	Output price	Energy price	Wage rate	Fertiliser price	Pesticide price	Services price	Rough-age price	Concen-trate feed price
Spring barley	0,255	-0,009	-0,088	-0,010	-0,009	-0,006	-0,001	-0,131
Winter barley	0,260	-0,009	-0,090	0,005	0,011	0,008	-0,007	-0,178
Wheat	0,275	-0,010	-0,083	-0,013	-0,009	-0,007	-0,001	-0,153
Pulses	0,200	-0,007	-0,069	-0,009	-0,019	-0,005	0,000	-0,090
Rape	0,350	-0,013	-0,121	-0,020	-0,011	-0,009	0,001	-0,177
Potatoes	0,005	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Sugar beets	0,005	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Dairy cattle	0,001	0,000	0,000	0,000	0,000	-0,001	0,000	0,001
Beef cattle	0,001	0,000	0,000	0,000	0,000	0,000	0,000	-0,001
Pigs	0,001	0,000	0,000	0,000	0,000	0,000	0,000	-0,001
Poultry	0,001	0,000	0,000	0,000	0,000	0,000	0,000	0,000

Table E.6. Yield elasticities, pig farms on sandy soil

	Output price	Energy price	Wage rate	Fertiliser price	Pesticide price	Services price	Rough-age price	Concen-trate feed price
Spring barley	0,255	-0,009	-0,090	-0,011	-0,005	-0,006	0,000	-0,134
Winter barley	0,260	-0,022	-0,088	-0,011	-0,005	-0,007	-0,001	-0,127
Wheat	0,275	-0,010	-0,093	-0,006	-0,011	-0,007	-0,002	-0,147
Pulses	0,200	-0,007	-0,068	-0,004	-0,008	-0,007	0,000	-0,105
Rape	0,350	-0,012	-0,100	-0,015	-0,010	-0,014	-0,001	-0,199
Potatoes	0,005	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Sugar beets	0,005	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Dairy cattle	0,001	0,000	0,000	0,000	0,000	0,000	0,000	-0,001
Beef cattle	0,001	0,000	0,000	0,000	0,000	0,000	0,000	-0,001
Pigs	0,001	0,000	0,000	0,000	0,000	0,000	0,000	-0,001
Poultry	0,001	0,000	-0,001	0,000	0,000	0,000	0,000	0,000

Table E.7. Yield elasticities, part time farms on loamy soil

	Output price	Energy price	Wage rate	Fertiliser price	Pesticide price	Services price	Rough-age price	Concen-trate feed price
Spring barley	0,255	-0,010	-0,141	-0,031	-0,012	-0,018	0,000	-0,043
Winter barley	0,260	-0,010	-0,144	-0,031	-0,012	-0,020	-0,001	-0,042
Wheat	0,275	-0,010	-0,152	-0,033	-0,015	-0,021	-0,001	-0,043
Pulses	0,200	-0,008	-0,111	0,005	-0,033	-0,015	-0,001	-0,038
Rape	0,350	-0,013	-0,177	-0,047	-0,017	-0,034	-0,001	-0,061
Potatoes	0,005	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Sugar beets	0,005	0,002	-0,037	0,024	0,000	0,017	-0,002	-0,008
Dairy cattle	0,001	0,000	-0,001	0,000	0,000	0,000	0,000	0,000
Beef cattle	0,001	0,000	-0,001	0,000	0,000	0,000	0,000	0,000
Pigs	0,001	0,000	0,000	0,000	0,000	0,000	0,000	-0,001
Poultry	0,001	0,000	-0,001	0,000	0,000	0,000	0,000	0,000

Table E.8. Yield elasticities, part time farms on sandy soil

	Output price	Energy price	Wage rate	Fertiliser price	Pesticide price	Services price	Rough-age price	Concen-trate feed price
Spring barley	0,255	-0,010	-0,141	-0,032	-0,009	-0,022	-0,001	-0,040
Winter barley	0,260	-0,010	-0,140	-0,034	-0,008	0,218	-0,001	-0,285
Wheat	0,275	-0,011	-0,149	-0,026	-0,028	-0,011	-0,001	-0,050
Pulses	0,200	-0,008	-0,108	-0,014	-0,014	-0,023	0,001	-0,033
Rape	0,350	-0,014	-0,167	-0,049	-0,016	-0,041	-0,002	-0,061
Potatoes	0,005	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Sugar beets	0,005	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Dairy cattle	0,001	0,000	-0,001	0,000	0,000	0,000	0,000	0,000
Beef cattle	0,001	0,000	-0,001	0,000	0,000	0,000	0,000	0,000
Pigs	0,001	0,000	0,000	0,000	0,000	0,000	0,000	-0,001
Poultry	0,001	0,000	0,000	0,000	0,000	0,000	0,000	0,000

Appendix F. Yield-endogenous price elasticities for variable input demands (Marshall elasticities)

Table F.1. Short run Marshallian input demand elasticities - crop farms on loamy soil

	Energy	Labour	Fertilisers	Pesti-cides	Services	Rough-age	Conc. feeds
Energy price	-0,314	-0,030	0,111	-0,047	0,040	0,039	0,002
Wage rate	-0,275	-0,130	0,054	-0,427	0,372	0,371	-0,410
Fertiliser price	0,342	0,018	-0,636	0,413	0,123	3,031	-0,182
Pesticide price	0,221	-0,083	0,238	-0,932	0,072	1,473	0,359
Services price	0,031	0,031	0,030	0,031	0,248	-7,668	-0,252
Roughage price	0,001	0,001	0,036	0,030	-0,365	-1,001	-0,945
Concentrate feed price	0,053	0,225	0,052	0,052	0,056	0,050	-0,642

Table F.2. Short run Marshallian input demand elasticities - cattle farms on loamy soil

	Energy	Labour	Fertilisers	Pesti-cides	Services	Rough-age	Conc. feeds
Energy price	-0,164	-0,022	0,044	0,044	0,040	0,043	-0,026
Wage rate	-0,208	-0,279	0,097	-0,633	0,431	0,398	0,216
Fertiliser price	0,142	0,034	-0,578	0,992	0,144	0,141	-0,149
Pesticide price	0,042	-0,066	0,294	-0,765	0,043	0,042	0,041
Services price	0,041	0,047	0,045	0,046	-0,964	0,812	0,026
Roughage price	0,002	0,002	0,002	0,002	0,043	-0,998	-1,014
Concentrate feed price	0,048	0,052	-0,357	1,028	0,046	0,051	0,198

Table F.3. Short run Marshallian input demand elasticities - cattle farms on loamy soil

	Energy	Labour	Fertilisers	Pesti-cides	Services	Rough-age	Conc. feeds
Energy price	-1,562	-0,005	0,328	0,028	0,028	0,030	0,087
Wage rate	-0,089	-0,242	-0,036	-1,115	0,460	0,481	0,234
Fertiliser price	0,536	0,002	-0,634	0,801	0,045	0,048	-0,026
Pesticide price	0,019	-0,046	0,327	-0,740	0,019	0,378	0,014
Services price	0,041	0,041	0,040	0,041	-0,591	0,043	-0,008
Roughage price	0,036	0,036	0,035	0,680	0,035	-1,569	-0,938
Concentrate feed price	-0,413	0,247	0,245	-1,437	0,245	0,276	0,403

Table F.4. Short run Marshallian input demand elasticities - cattle farms on sandy soil

	Energy	Labour	Fertilisers	Pesti-cides	Services	Rough-age	Conc. feeds
Energy price	-0,458	-0,005	0,150	-0,104	0,029	-0,216	0,024
Wage rate	-0,084	-0,193	-0,155	-1,070	0,449	0,449	0,195
Fertiliser price	0,354	-0,023	-0,468	0,439	0,068	1,018	0,004
Pesticide price	-0,056	-0,036	0,099	-0,729	0,014	0,492	0,036
Services price	0,048	0,047	0,048	0,045	-0,622	0,048	0,000
Roughage price	-0,130	0,017	0,258	0,554	0,017	-2,200	-0,981
Concentrate feed price	0,475	0,279	0,269	0,255	0,269	-1,065	0,307

Table F.5. Short run Marshallian input demand elasticities - pig farms on loamy soil

	Energy	Labour	Fertilisers	Pesti-cides	Services	Rough-age	Conc. feeds
Energy price	-0,365	0,032	0,032	0,032	0,032	0,031	-0,011
Wage rate	0,308	-0,115	-0,010	-0,548	0,312	0,304	0,001
Fertiliser price	0,041	-0,001	-0,079	0,040	0,041	0,046	-0,009
Pesticide price	0,028	-0,051	0,028	-0,704	0,028	0,033	0,065
Services price	0,022	0,023	0,022	0,022	0,270	0,026	-0,038
Roughage price	0,002	0,002	0,002	0,002	0,002	-1,001	-0,998
Concentrate feed price	0,437	0,440	-0,532	-0,335	0,445	0,420	0,570

Table F.6. Short run Marshallian input demand elasticities - pig farms on sandy soil

	Energy	Labour	Fertilisers	Pesti-cides	Services	Rough-age	Conc. feeds
Energy price	-0,242	0,011	-0,170	0,031	0,032	0,032	0,014
Wage rate	0,109	-0,078	-0,030	-0,417	0,308	0,315	-0,007
Fertiliser price	-0,204	-0,004	-0,151	0,593	0,039	2,090	-0,010
Pesticide price	0,018	-0,025	0,283	-0,983	0,018	0,018	0,024
Services price	0,023	0,023	0,023	0,022	0,102	0,023	-0,027
Roughage price	0,002	0,002	0,100	0,002	0,002	-0,998	-1,006
Concentrate feed price	0,068	0,475	-0,030	0,063	1,198	3,430	0,511

Table F.7. Short run Marshallian input demand elasticities - parttime farms on loamy soil

	Energy	Labour	Fertilisers	Pesti-cides	Services	Rough-age	Conc. feeds
Energy price	-0,696	-0,031	0,253	0,027	0,028	0,034	-0,002
Wage rate	-0,455	-0,358	0,110	-0,069	0,414	0,481	0,181
Fertiliser price	0,805	0,024	-0,750	0,357	0,088	0,109	-0,055
Pesticide price	0,035	-0,006	0,142	-0,967	0,035	0,041	0,095
Services price	0,055	0,056	0,055	0,054	-0,699	0,067	-0,060
Roughage price	0,004	0,003	0,004	0,003	0,004	0,253	-1,028
Concentrate feed price	0,077	0,077	0,077	0,074	0,077	0,098	0,075

Table F.8. Short run Marshallian input demand elasticities - part time farms on sandy soil

	Energy	Labour	Fertilisers	Pesti-cides	Services	Rough-age	Conc. feeds
Energy price	-0,398	-0,011	0,093	0,027	0,031	0,031	-0,015
Wage rate	-0,156	-0,272	-0,170	0,375	0,428	0,428	0,030
Fertiliser price	0,308	-0,041	-0,474	0,656	0,104	0,103	0,084
Pesticide price	0,022	0,022	0,163	-0,985	-0,160	0,023	0,008
Services price	0,067	0,067	0,068	-0,426	-0,943	0,069	0,165
Roughage price	0,004	0,004	0,004	0,004	0,004	-0,996	-0,996
Concentrate feed price	0,067	0,066	-0,502	-0,699	0,079	0,069	0,636